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TECHNICAL REPORT HL-79-15

SAN JUAN NATIONAL HISTORIC SITE SAN JUAN, PUERTO RICO DESIGN FOR PREVENTION OF WAVE-INDUCED EROSION

Hydraulic Model Investigation

by

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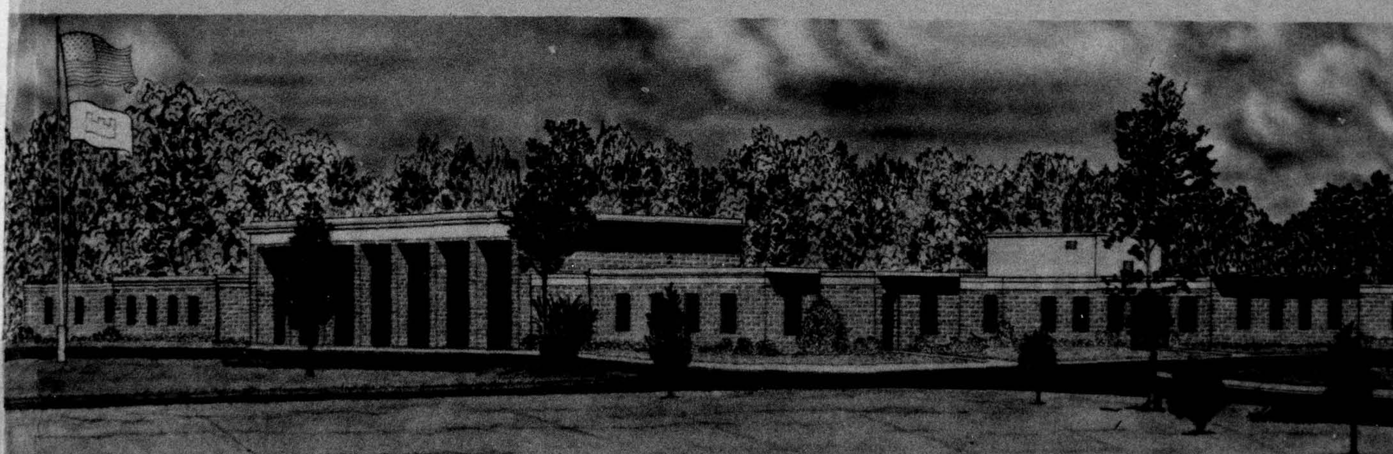
September 1979
Final Report

Approved For Public Release; Distribution Unlimited



Prepared for U. S. Army Engineer District, Jacksonville
Jacksonville, Florida 32201
and
The National Park Service, Southeast Regional Office
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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

A 1:75-scale (undistorted) hydraulic model of the San Juan National Historic Site, which included the entire historic site, the entrance to San Juan Harbor, part of Isla de Cabras, and sufficient offshore area in the Atlantic Ocean to permit generation of the required test waves, was used to investigate the effects of proposed structures on wave attack at the historic site. Proposed improvement plans consisted of the installation of rubble-mound revetments and/or breakwaters on both the ocean and bay sides (Continued)

CONT'

411 389 LB

20. ABSTRACT (Continued).

of El Morro Castle. A 90-ft-long wave generator and an automated data acquisition and control system (ADACS) were utilized in model operation. It was concluded from model test results that:

a. Existing conditions are characterized by very rough and turbulent wave conditions along the San Juan National Historic Site during periods of moderate to large wave attack.

b. Tests involving the revetment plan (Plan 1) indicated that a 15-ft-high revetment was the optimum with respect to wave runup data obtained (i.e. maximum runup came to the top of the revetment but did not overtop in most cases).

c. Of the improvement plans involving a shore-connected breakwater (Plans 2-2G), it was determined that increasing the width or raising the seaward edge of the breakwater, to achieve the wave-runup criteria, would require a significantly larger volume of rock than would the other plans tested.

d. Of the improvement plans involving an offshore breakwater north of El Morro and around El Morro point (Plans 3-3D), it was determined that at least a 6-ft breakwater crest elevation (Plan 3D) was required to maintain an average runup value at the shoreline of less than 5 ft (original runup criterion).

e. Of the improvement plans involving a 15-ft-high revetment and a breakwater north of El Morro (Plans 4-4B), it was determined that the revetment elevation could be reduced in the lee of the breakwater based on the maximum runup obtained for the corresponding plan.

f. Of the improvement plans involving an offshore breakwater north of El Morro and around the point with a transition to a 15-ft-high west shore revetment (Plans 5-5C), it was determined that a 5.5-ft breakwater crest elevation (Plan 5C) resulted in average runup at the point of 5.2 ft (slightly above the original 5.0-ft criterion).

g. Of the improvement plans involving an offshore breakwater extending around the point and to the west and north of El Morro with no revetment (Plans 6-6B), it was determined that an 8-ft breakwater crest elevation (Plan 6B) would most nearly meet the desired criterion of 5.0 ft (average wave runup was 5.5 ft at the point).

h. Of the improvement plans involving an offshore breakwater in conjunction with a revetment at the shoreline north of El Morro and around the point and a west shore revetment (Plans 7A-7D), it was determined that either Plan 7A or 7B would be effective in reducing wave runup to an acceptable level (considering the revised wave-runup criterion of 10 ft north of El Morro and westward around the point).

i. The removal of 161 ft of structure from the eastern end of the offshore breakwater (Plan 7D) will result in wave runup within the revised criterion (12 ft) at the shoreline behind the removed structure.

j. The installation of any of the major improvement plans tested should have no adverse effect on waves in the entrance to San Juan Bay or on currents around El Morro Castle.

PREFACE

In October 1974 Congress authorized the Secretary of the Interior in cooperation with the Secretary of the Army to conduct studies to determine the cause and extent of damage to the historic structures of the San Juan National Historic Site. As part of these investigations, a sequence of model studies was agreed upon to provide data that would determine the most suitable plan for shore protection and restoration of the foundation walls along the shores of the historic site.

A request for a three-dimensional model investigation of the San Juan National Historic Site was initiated by the District Engineer, U. S. Army Engineer District, Jacksonville (SAJ). Funds for the U. S. Army Engineer Waterways Experiment Station (WES) to conduct the study were authorized on 29 July 1977.

The model study was conducted during the period December 1977-July 1979 by personnel of the Wave Processes Branch (WPB), Wave Dynamics Division (WDD), Hydraulics Laboratory, WES, under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory; Mr. F. A. Herrmann, Assistant Chief of the Hydraulics Laboratory; Dr. R. W. Whalin, Chief of the WDD; and Mr. C. E. Chatham, Jr., Chief of the WPB. The tests were conducted by Mr. H. F. Acuff, Civil Engineering Technician, with the assistance of Messrs. R. E. Ankeny, Computer Technician, and L. L. Friar, Electronics Technician, under the supervision of Mr. Robert R. Bottin, Jr., Project Manager. This report was prepared by Mr. Bottin.

Prior to the model investigation, Mr. Bottin visited the SAJ office and the San Juan National Historic Site to confer with representatives of SAJ and to inspect the prototype site. During the course of the investigation, liaison between SAJ and WES was maintained by means of conferences, telephone communications, and monthly progress reports.

Mr. Jim Robinson of the South Atlantic Division (SAD); Messrs. Andrew O. Hobbs, Charles F. Stevens, A. Ira Foster, and Glen Lane of SAJ; Messrs. William W. Smith, Jim Bainbridge, David G. Wright, Henry A. Judd, Lloyd K. Whitt, John C. Garner, Jr., William C. Sowers,

Gerry Parrilla, Marion W. Harris, and Dan Lee of the National Park Service; Mr. John J. Cullinane of the Advisory Council on Historic Preservation; and Mr. Gus Pantel of the Office of the Governor, San Juan, Puerto Rico, visited WES to observe model operation and participate in conferences during the course of the model study.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, C.E. Technical Director was Mr. Fred R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
miles (U. S. statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms
square feet	0.09290304	square metres
square miles (U. S. statute)	2.589988	square kilometres
tons (2000 lb, mass)	907.1847	kilograms

SAN JUAN NATIONAL HISTORIC SITE

SAN JUAN, PUERTO RICO

DESIGN FOR PREVENTION OF WAVE-INDUCED EROSION

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The San Juan National Historic Site is located at the old city of San Juan on the north coast of the Island of Puerto Rico (Figure 1).

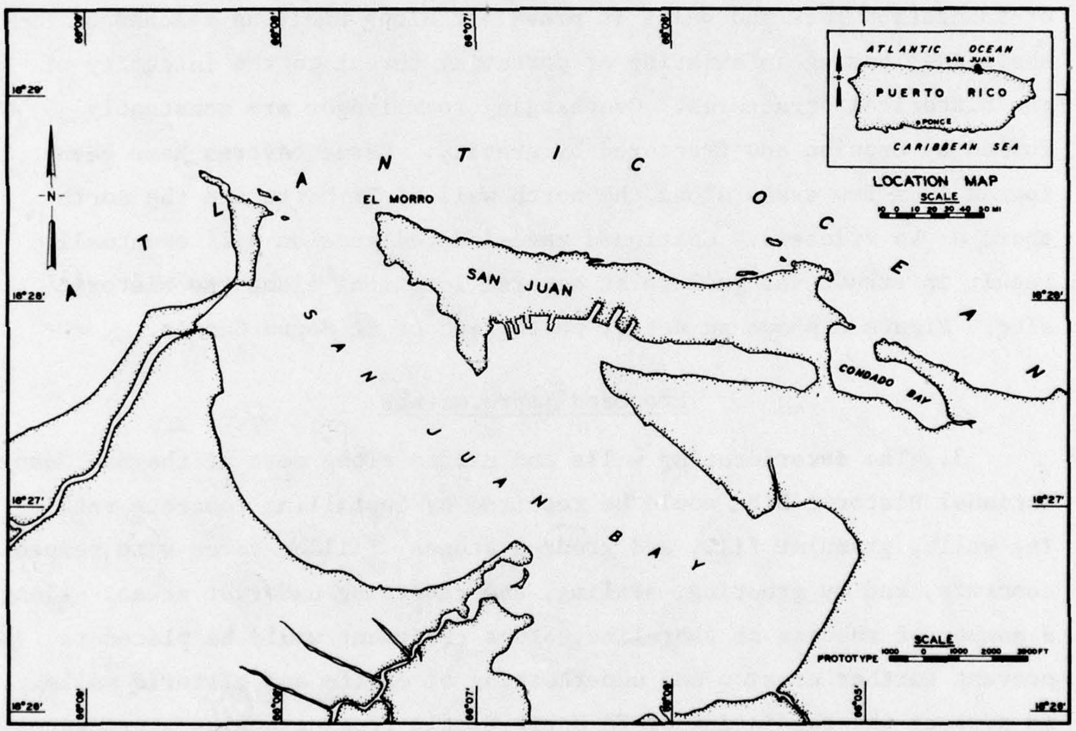

Figure 1. Project location

The area is part of a fortification complex built by the Spanish for defense of the city and as a base to support Spanish influence in the Americas. Construction of the fortifications started in the 16th century

with most of the major works existing today completed late in the 17th century. Included in the San Juan National Historic Site are the fortifications of La Princesa, San Cristobal, Castillo de San Felipe del Morro (El Morro Castle), and numerous connecting walls and bastions. The walls extend along the Atlantic coast and the shoreline of San Juan Bay for a distance of about 4 miles.* To ensure preservation of the defenses, the San Juan National Historic Site was established by the Secretary of Interior on 14 February 1949 (USAED, Jacksonville, 1974).

The Problem

2. The cliffs adjacent to the San Juan National Historic Site suffer severe scour and erosion due to direct wave attack. Undercutting of foundation rock and walls is prevalent along numerous reaches of shoreline, posing an existing or potential threat to the integrity of the historical structures. Overhanging rock ledges are constantly formed by erosion and fractured by gravity. Large caverns have been formed in a few areas along the north wall of El Morro and the north shore of La Princesa. Continued wave-induced erosion will eventually result in structural failure at several locations along the historic site. Figure 2 shows an aerial photograph of El Morro Castle.

Proposed Improvements

3. The deteriorating walls and cliffs along most of the San Juan National Historic Site would be repaired by installing concrete retaining walls, granular fill, and grouted stones, filling caves with pumped concrete, and by grouting, sealing, and revetting undercut areas. Along a number of reaches of shoreline, stone revetment would be placed to prevent further erosion and undercutting of cliffs and historic walls. To protect the foundation of El Morro Castle from attacking storm waves, construction of an offshore breakwater and/or revetment is proposed. These structures would be located on both the ocean and bay sides of El Morro.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

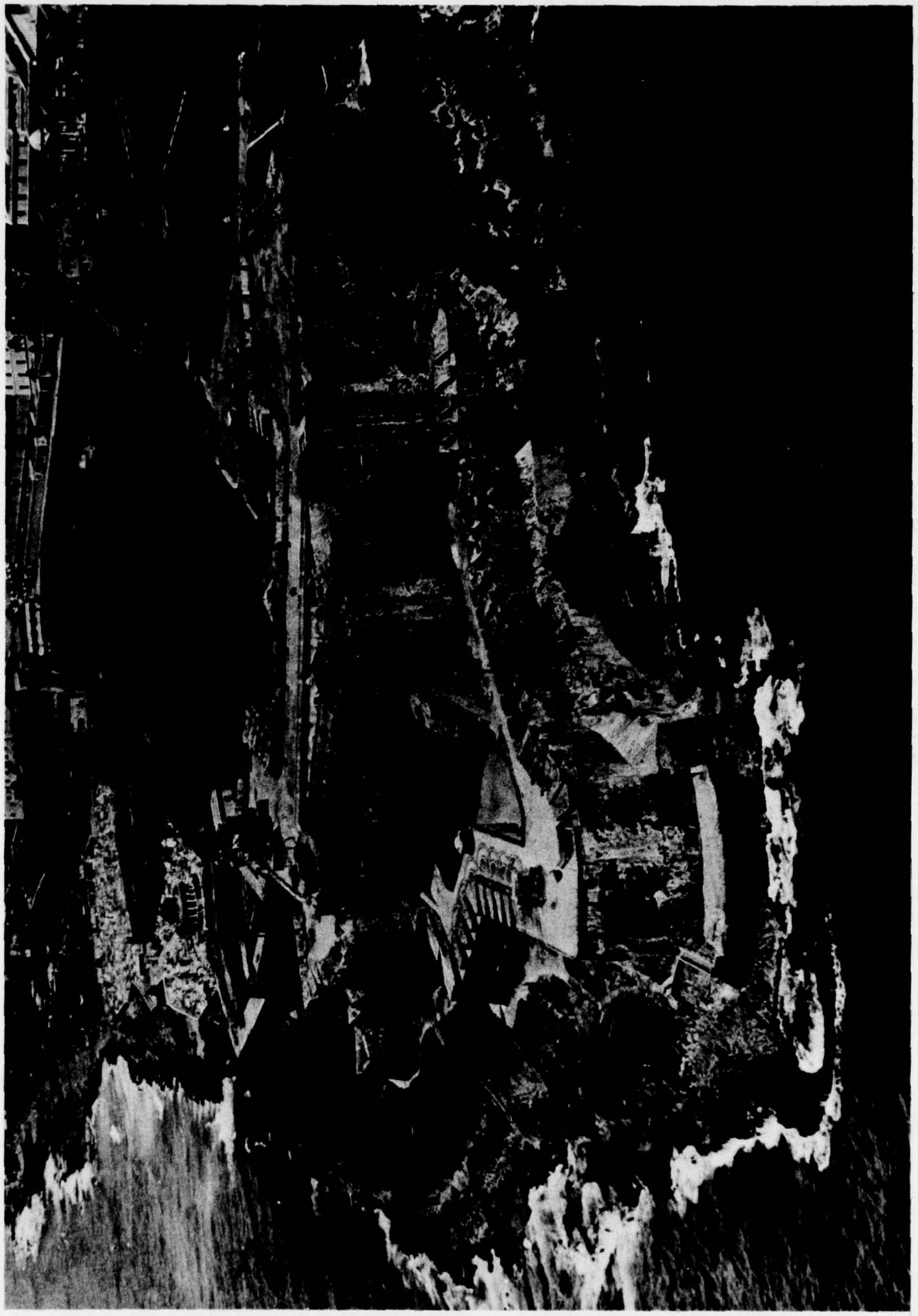

Figure 2. Aerial photograph of El Morro

Purpose of the Model Study

4. At the request of the U. S. Army Engineer District, Jacksonville (SAJ), a hydraulic model study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) to:

- a. Determine the optimum location, orientation, length, width, and crest elevation of various offshore breakwater and/or revetment structures installed around El Morro with respect to shore protection and economics.
- b. Determine design wave heights at various locations along the San Juan National Historic Site.

Wave-Runup Criteria

5. For the study reported herein, SAJ initially specified that for an offshore breakwater plan to be acceptable, wave runup on the exposed cliff face should not exceed 5.0 ft. Where a revetment plan was installed along the shoreline (either alone or in combination with a breakwater), wave runup was not to overtop the crest elevation of the revetment. After testing of the initially proposed plans and based on geotechnical information obtained at the site during model testing, wave-runup criteria for Plans 7-7D were revised as follows:

Location	Maximum Runup Allowed
North shoreline immediately eastward of El Morro Castle	12 ft
Shoreline north of El Morro Castle and westward around point	10 ft

PART II: THE MODEL

Design of Model

6. The San Juan National Historic Site model (Figure 3) was constructed to an undistorted linear scale of 1:75, model to prototype. Scale selection was based on such factors as:

- a. Depth of water required in the model to prevent excessive bottom friction.
- b. Absolute size of model waves.
- c. Available shelter dimensions and area required for model construction.
- d. Efficiency of model operation.
- e. Available wave-generating and wave-measuring equipment.
- f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of short-period wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). The scale relations used for design and operation of the model were as follows:

Characteristic	Dimension*	Model:Prototype Scale Relation
Length	L**	$L_r = 1:75$
Area	L^2	$A_r = L_r^2 = 1:5,625$
Volume	L^3	$\forall_r = L_r^3 = 1:421,875$
Time	T	$T_r = L_r^{1/2} = 1:8.66$
Velocity	L/T	$V_r = L_r^{1/2} = 1:8.66$

* Dimensions are in terms of length and time.
** For convenience, symbols and unusual abbreviations are listed and defined in the Notation (Appendix B).

7. The proposed improvement plans for the San Juan National Historic Site included the use of rubble-mound breakwaters and/or

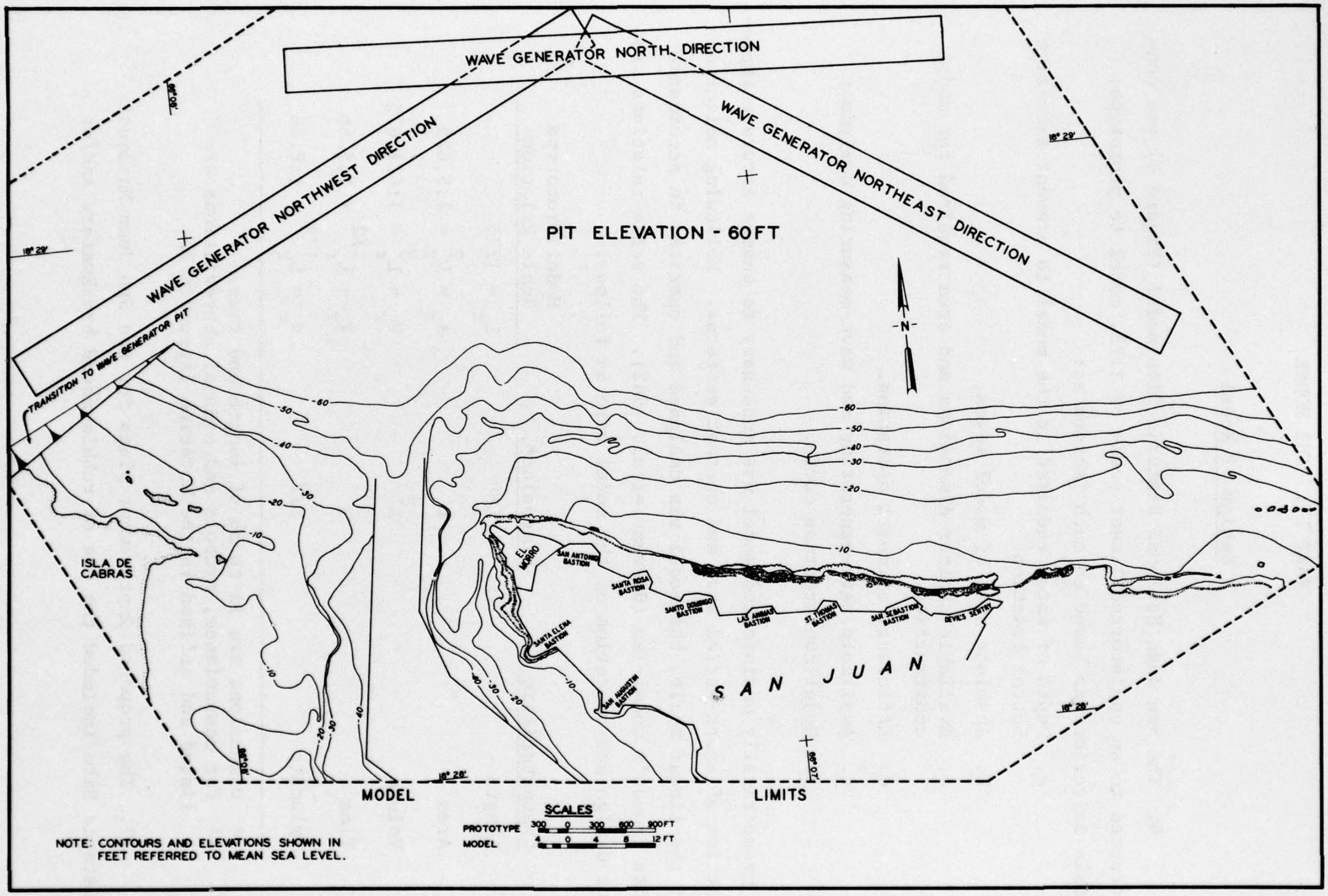

Figure 3. Model layout

revetments. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus the transmission and absorption of wave energy became a matter of concern in design of the 1:75-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (LeMehauté 1965). Also the transmission of wave energy through the breakwater is relatively less for the small-scale model than that for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations (Dai and Jackson 1966, Brasfeild and Bell 1967) at WES, this adjustment was made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A breakwater section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for breakwaters and wave conditions similar to those at San Juan, it was determined that a close approximation of the correct wave-energy transmission characteristics would be obtained by increasing the size of the rock used in the 1:75-scale model to approximately one and a half that required for geometric similarity. Accordingly, in constructing the breakwater structures in the San Juan National Historic Site model, the rock sizes were computed linearly by scale, then multiplied by 1.5 to determine the actual sizes to be used in the model.

The Model and Appurtenances

8. The model, which was molded in cement mortar, reproduced the entire San Juan National Historic Site, the entrance to San Juan Harbor, part of Isla de Cabras, and underwater contours to an offshore depth of 60 ft. The total area reproduced in the model was approximately 18,620 sq ft, representing about 3.75 square miles in the prototype.

Figure 4 shows a general view of the model. Vertical control for model construction was based on mean sea level datum.* Horizontal control was referenced to a local prototype coordinate system.

9. Model waves were generated by a 90-ft-long wave generator with a trapezoidal-shaped, vertical-motion plunger. The vertical movement of the plunger caused a periodic displacement of water incident to this motion. The length of stroke and the frequency of the vertical motion were variable over the range necessary to generate waves with the required characteristics. In addition, the wave generator was mounted on retractable casters which enabled it to be positioned to generate waves from the required directions.

10. An Automated Data Acquisition and Control System (ADACS), designed and constructed at WES (Figure 5), was used to secure wave-height data at selected locations in the model. Basically, through the use of a minicomputer, ADACS recorded onto magnetic tape the electrical output of parallel-wire, resistance-type sensors that measured the change in water-surface elevation with respect to time. The magnetic tape output was then analyzed to obtain the required data.

11. A 2-ft (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen any wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

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* All elevations (el) cited herein are in feet referred to mean sea level (msl) unless otherwise defined.

Figure 4. General view of model

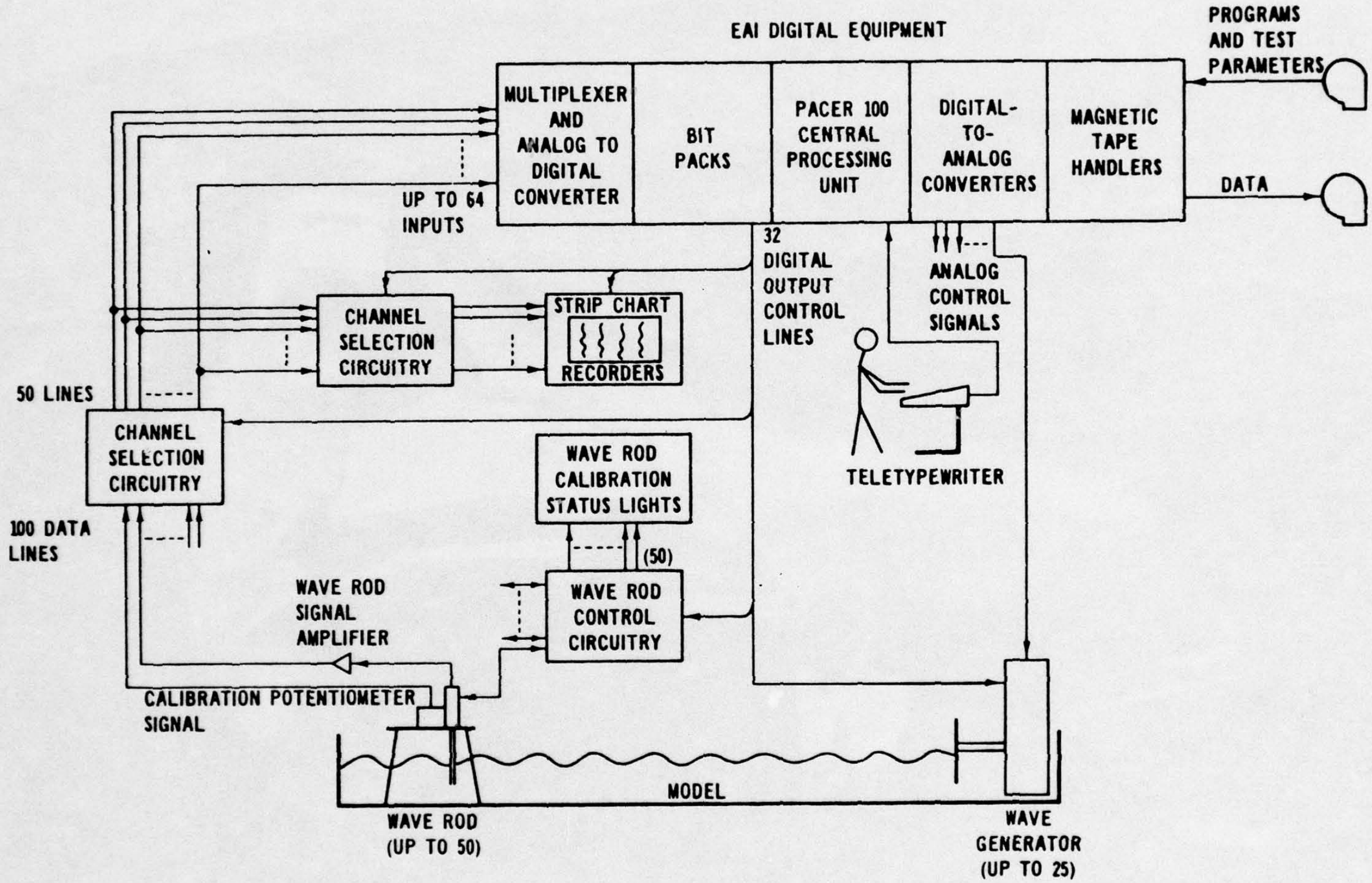

Figure 5. Automated Data Acquisition and Control System (ADACS)

PART III: TEST CONDITIONS AND PROCEDURES

Selection of Test Conditions

Still-water level

12. Still-water levels (swl's) for wave action models are selected so that the various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include the refraction of waves in the project area, the overtopping of structures by the waves, the reflection of wave energy from various structures, and the transmission of wave energy through porous structures.

13. It is desirable to select a model swl that closely approximates the higher water stages which normally occur in the prototype for the following reasons:

- a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tide cycle.
- b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind tide and shoreward mass transport.
- c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.
- d. When a high swl is selected, a model investigation tends to yield more conservative results.

14. A swl of 1.1 ft msl was selected for use during model testing. This value was obtained by combining mean high water (0.6 ft) with a 0.5-ft short-period rise in local water level due to wind tide. The normal tide range at San Juan is 1.1 ft (mean low water to mean high water).

Factors influencing selection of test wave characteristics

15. In planning the testing program for a model investigation of wave-action problems, it is necessary to select dimensions and directions for the test waves that will allow a realistic test of proposed improvement plans and an accurate evaluation of the elements of the various proposals. Surface wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions

between individual wave components. The height and period of the maximum wave that can be generated by a given storm depends on the wind speed, the length of time that wind of a given speed continues to blow, and the water distance (fetch) over which the wind blows. Selection of test conditions entails evaluation of such factors as:

- a. The fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can attack the problem area.
- b. The frequency of occurrence and duration of storm winds from the different directions.
- c. The alignments, lengths, and locations of various reflecting surfaces in the area.
- d. The refraction of waves caused by differentials in depth in the area seaward of the project location, which may create either a concentration or diffusion of wave energy at the site.

Wave refraction

16. When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. The change in wave height and direction can be determined by plotting refraction diagrams and calculating refraction coefficients. These diagrams are constructed by plotting the position of wave orthogonals (lines drawn perpendicular to wave crests) from deep water into shallow water. If it is assumed that waves do not break and that there is no lateral flow of energy along the wave crest, the ratio between the wave height in deep water (H_o) and the wave height at any point in shallow water (H) is inversely proportional to the square root of the ratio of the corresponding orthogonal spacings (b_o and b), or $H/_o = K_s(b_o/b)^{1/2}$. The quantity $(b_o/b)^{1/2}$ is the refraction coefficient, K_r ; K_s is the shoaling coefficient. Thus, the refraction coefficient multiplied by the shoaling coefficient gives a conversion factor for transfer of deepwater wave heights to shallow-water values.

The shoaling coefficient, which is a function of wavelength and water depth, can be obtained from CERC (1973). For this study, refraction diagrams were prepared for representative wave periods from the critical directions of approach using computer facilities at WES and are detailed in Appendix A.

Prototype wave data and selection of test waves

17. Measured prototype wave data on which a comprehensive statistical analysis of wave conditions could be based were unavailable for the San Juan area. However, deepwater wave hindcast data for this area were obtained from National Climatic Data (1976). From this reference, the characteristics of waves were obtained from an analysis of shipboard observations which provide good coverage of all synoptic events of importance to the San Juan area with the exception of hurricanes. Deepwater wave data are summarized in Table 1. These data were converted to shallow-water values (Table 2) by the application of refraction and shoaling coefficients. The characteristics of test waves used in the model, selected from Table 2, are shown in the following tabulation:

Deepwater Direction, deg	Selected Shallow-Water Test Direction, deg	Selected Test Waves Period, sec	Selected Test Waves Height, ft
Northwest, 315	334	5	6, 12*
		7	8, 16
		9	8, 16
		11	6, 12
		13	8, 16
		15	6, 10
		17	4, 8
		19	4
North, 0	3	5	6, 12*
		7	8, 16
		9	8, 16, 22
		11	8, 16
		13	9, 18
		15	9, 18
		17	6, 12
		19	4, 8

(Continued)

* Steepness limited wave.

Deepwater Direction, deg	Selected Shallow-Water Test Direction, deg	Selected Test Waves	
		Period, sec	Height, ft
Northeast, 45	33	5	6, 12*
		7	8, 16
		9	9, 18
		11	10, 22
		13	9, 18
		15	7, 14
		17	6, 12
		19	6, 11

* Steepness limited wave.

18. During the course of the model investigation, SAJ requested that 10-sec, 12-ft test waves also be used while obtaining wave runup data. Consequently, these test waves from the northwest, north, and northeast also were tested in the model.

19. In addition to the test waves listed in paragraphs 17 and 18, 9-sec, 29-ft test waves (maximum capability of the wave generator for this wave period) were generated from the northeast for existing conditions to determine design wave heights at the shoreline.

Analysis of Model Data

20. Relative merits of the various plans were evaluated by:

a. Comparison of wave runup at selected locations in the model.

b. Comparison of wave heights at selected locations in the model.

c. Comparison of wave-induced current patterns and magnitudes.

d. Visual observations and wave pattern photographs.

In analyzing the wave-height data, the average height of the highest one third of the waves recorded at each gage location was selected. All wave heights thus selected then were adjusted to compensate for wave-height attenuation due to viscous bottom friction in the model by application of Keulegan's equation (Keulegan 1950). From this equation, reduction of wave heights in the model can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and

distance of wave travel. Wave runup was secured by establishing elevations on the model overbank and/or proposed revetment and visually recording maximum values at the selected gage locations. Wave-induced current magnitudes were obtained by timing the progress of an injected dye tracer relative to a thin graduated scale placed on the model floor.

PART IV: TESTS AND RESULTS

The Tests

Existing conditions

21. Prior to tests of various improvement plans, comprehensive tests were conducted for existing conditions. Wave-height and wave-runup data were obtained at various locations along the historic site (Plate 1) for the test directions listed in paragraph 17. Wave-induced current patterns and magnitudes, wave pattern photographs, and model motion picture footage also were secured for representative waves from the three selected test directions.

Improvement plans

22. Wave-runup tests were conducted for 29 variations in the design elements of 7 basic shore protection plans. These variations consisted of changes in the location, lengths, widths, and/or crest elevations of the various breakwater and revetment plans. Wave-height data, wave-induced current patterns and magnitudes, wave pattern photographs, and model movie footage were obtained for the more important improvement plans. Brief descriptions of the improvement plans are presented in the following subparagraphs; dimensional details are presented in Plates 2-12.

- a. Plan 1 (Plate 2) consisted of a 15-ft-high revetment along the north and west sides of El Morro and around El Morro point.
- b. Plan 2 (Plate 3) involved a shore-connected breakwater (el -0.6 ft) north of El Morro and around El Morro point with a 15-ft-high revetment along the west side of El Morro.
- c. Plan 2A (Plate 3) entailed the elements of Plan 2 with the crest of the shore-connected breakwater raised to el 0.6 ft.
- d. Plan 2B (Plate 4) included the elements of Plan 2 but the breakwater width was increased by 60 ft around El Morro point, resulting in a 175-ft-wide structure.

e. Plan 2C (Plate 4) entailed the elements of Plan 2B with an additional 75 ft of breakwater width added around El Morro point.

f. Plan 2D (Plate 4) involved the elements of Plan 2C with an additional 75 ft of breakwater width added around the entire shore-connected breakwater structure.

g. Plan 2E (Plate 4) consisted of the elements of Plan 2D with the breakwater crest raised to el 0.6 ft.

h. Plan 2F (Plate 5) entailed the elements of Plan 2C, but at the seaward edge of the breakwater, the crest was raised to el 7.2 ft with a crest width of 23.5 ft.

i. Plan 2G (Plate 5) involved the elements of Plan 2D with the seaward edge of the breakwater crest raised to el 7.2 ft with a crest width of 23.5 ft.

j. Plan 3 (Plate 6) consisted of a 15-ft-high revetment on the west side of El Morro and a detached offshore breakwater (crest el -0.6 ft and crest width 40 ft) around the point and north of El Morro.

k. Plan 3A (Plate 6) included the elements of Plan 3 but the detached breakwater crest was raised to el 4 ft.

l. Plan 3B (Plate 6) entailed the elements of Plan 3 with the breakwater crest raised to el 8 ft.

m. Plan 3C (Plate 6) involved the elements of Plan 3 except the breakwater crest was raised to el 12 ft.

n. Plan 3D (Plate 6) entailed the elements of Plan 3 with the breakwater crest raised to el 6 ft.

o. Plan 4 (Plate 7) consisted of a 15-ft-high revetment along the north and west sides of El Morro and around El Morro point, with a breakwater (crest el -0.6 ft) north of El Morro.

p. Plan 4A (Plate 7) included the elements of Plan 4 but the breakwater crest was raised to el 4 ft.

q. Plan 4B (Plate 7) entailed the elements of Plan 4 with the breakwater crest raised to el 8 ft.

r. Plan 5 (Plate 8) consisted of a 15-ft-high west shore revetment with a transition to an offshore breakwater (crest el -0.6 ft) extending around the point and north of El Morro.

s. Plan 5A (Plate 8) entailed the elements of Plan 5 except the breakwater crest was raised to el 4 ft.

t. Plan 5B (Plate 8) involved the elements of Plan 5 with the breakwater crest raised to el 8 ft.

u. Plan 5C (Plate 8) included the elements of Plan 5 with the breakwater crest raised to el 5.5 ft.

v. Plan 6 (Plate 9) consisted of an offshore breakwater (crest el 0.6 ft) extending around the point to the west and north of El Morro.

w. Plan 6A (Plate 9) entailed the elements of Plan 6 with the breakwater crest raised to el 4 ft.

x. Plan 6B (Plate 9) involved the elements of Plan 6 with the breakwater crest raised to el 8 ft.

y. Plan 7 (Plate 10) consisted of a revetment along the north and west sides of El Morro and around the point. The elevation of the revetment north of El Morro varied and was the same as top of the existing ledge (2 to 5 ft). The revetment crest elevation transitioned from the top of the ledge to 6 ft at the Floating Battery and to 15 ft within a distance of approximately 500 ft south of southwest tip of the Floating Battery. The crest elevation of the remaining length of the revetment south to Santa Elena was 15 ft and the entire revetment along the west shore had a 15-ft crest width.

z. Plan 7A (Plate 11) entailed the elements of Plan 7 with a 900-ft-long offshore breakwater (crest el 2.0 ft) installed north of El Morro and around the point.

aa. Plan 7B (Plate 12) involved the elements of Plan 7A with the east end of the offshore breakwater realigned and connected to the shore revetment. The breakwater crest elevation sloped to 0.0 ft at the shore connection.

bb. Plan 7C (Plate 11) entailed the elements of Plan 7A but the crest elevation of revetment north of El Morro was reduced to 0.0 ft.

cc. Plan 7D (Plate 11) involved the elements of Plan 7C except 161 ft was removed from the eastern end of the offshore breakwater and the revetment north of El Morro was changed as follows:

(1) Crest elevation was raised to 3.0 ft along the north shore where the elevation of the ledge was above or equal to 3.0 ft.

(2) Crest elevation was raised to the top of the ledge along the north shore where the elevation of the ledge was below 3.0 ft.

Wave-height tests

23. Wave-height tests for the various improvement plans were conducted using test waves from one or more of the test directions listed

in paragraph 17. Tests conducted for Plan 2 were limited to the most critical direction of wave approach (i.e. north). However, the more important improvement plans (Plans 1 and 7A) were tested comprehensively for the test waves from all three test directions (i.e., northwest, north, and northeast). Wave gage locations for various improvement plans are shown in Plates 2, 3, and 11.

Wave-induced current
<u>pattern and magnitude tests</u>

24. Wave-induced current patterns and magnitudes were determined at selected locations by timing the progress of a dye tracer relative to a known distance on the model surface. These were conducted for the best improvement plans using representative test waves from the three test directions.

<u>Wave-runup tests</u>

25. Wave-runup tests were conducted for the various improvement plans using one or more of the test directions listed in paragraph 17. Tests involving certain proposed test plans were limited to representative test waves from the most critical directions with respect to wave runup (i.e. north and northwest). The major improvement plans were tested comprehensively for test waves from all three directions (i.e, northwest, north, and northeast). Wave-runup gage locations for the various test plans are shown in Plates 2-12.

<u>Motion picture</u>

26. A motion picture entitled, "Hydraulic Model Investigation of San Juan National Historic Site, San Juan, Puerto Rico," was produced and forwarded to SAJ for use in briefings, public meetings, etc. The footage included a sound track with narrative description identifying the following:

- <u>a</u>. Background information.
- <u>b</u>. The problem.
- <u>c</u>. Proposed solutions.
- <u>d</u>. Design and construction of the model.
- <u>e</u>. Appurtenances used in the model.

f. Methods of obtaining wave heights, wave runup, and wave-induced current patterns and magnitudes.

g. Definition of wave height and wave period.

h. Various waves approaching El Morro Castle for existing conditions and major improvement plans.

The movie utilized "split screen" techniques to provide comparisons of existing conditions with each major improvement plan, and animation to depict elements of the various plans.

Emergency repairs
at Santa Elena Bastion

27. During the course of the model investigation, emergency repairs were initiated at Santa Elena Bastion (located south of and adjacent to the proposed improvements at El Morro Castle). Consequently, these repairs (consisting of a revetment around Santa Elena Bastion) were installed in the model prior to testing of the various improvement plans.

Test Results

28. In evaluating test results, the relative merits of various plans were based on measured wave heights, wave runup, and wave-induced current patterns and magnitudes. Model wave heights (significant wave height or $H_{1/3}$) were tabulated to show measured values at selected locations. Wave runup was plotted graphically to show runup elevations along the north and west sides of El Morro and around El Morro point. Wave-induced current patterns and magnitudes were superimposed on wave pattern photographs for the corresponding plan and wave condition tested.

Existing conditions

29. Wave-height measurements obtained for existing conditions (gages 1-39) are presented in Tables 3-7. Maximum wave heights obtained in the vicinity of the proposed breakwaters (gages 6-13) from the various directions were 19.7 ft (gage 10) for 11-sec, 12-ft waves from the northwest; 24.4 ft (gage 11) for 15-sec, 18-ft waves from the north; and 21.7 ft (gage 11) for 15-sec, 14-ft waves from the northeast. The

maximum wave height obtained along the historic site east of El Morro (gages 18-39) was 16.7 ft (gage 38) for 15-sec, 6-ft test waves from the northwest.

30. Maximum wave heights at various gage locations may appear excessive (i.e. greater than the normally accepted criterion of 0.78 times the depth) based on the depth of water at the gages. One or more of the following factors contribute to these large wave heights.

- a. Surge created by breaking waves approaching the shoreline resulting in greater depths at the gages than those at swl.
- b. Waves peaking and breaking directly on a particular gage.
- c. Waves reflected from the steep shoreline meeting incident waves (antinode of standing wave system) at particular gage locations.

The water depth (swl) and maximum wave height obtained at each gage location along with the test wave condition that produced the maximum height are presented in Table 8. While the effects of items b and c above on structural stability are uncertain, the use of the measured values for design wave heights should be conservative (i.e. they are as large or larger than the normal progressive wave height used in design manuals).

31. Wave-runup measurements obtained for existing conditions are shown in Plates 13-55. A maximum runup of 30 ft occurred for several of the test waves at and/or slightly north of El Morro point. Observations revealed large quantities of water running into the Floating Battery.

32. Wave-induced current patterns and magnitudes secured for existing conditions are shown in Photos 1-18. Maximum velocities obtained were 13.2, 10.8, and 7.9 fps at the shoreline north of El Morro, the area around the point (Floating Battery), and the shoreline west of El Morro, respectively. Typical wave patterns for existing conditions also are shown in Photos 1-18.

33. Using wave-height data obtained for existing conditions in the vicinity of the proposed revetments and breakwaters, stone sizes for the various structures were calculated by WES personnel using design procedures from CERC (1973) as follows:

Location	Design Wave Height Used	Armor Layer tons	Underlayer lb	Core Stone lb
Santa Elena	9.8	1.9	376	19
Revetment west of El Morro	12.2	4.3	858	43
Revetment north of El Morro	19.6	15.0	3010	150
Breakwater north of El Morro	19.6	22.6	4516	226

Improvement plans

34. Results of wave-height tests with Plan 1 installed in the model are presented in Tables 9 and 10. The maximum wave height obtained north of El Morro (gages 9-13) was 22.5 ft (gage 9) for 19-sec, 8-ft test waves from the north; and the maximum wave height obtained west of El Morro (gages 5, 6, and 8) was 15.0 ft (gage 6) for 13-sec, 16-ft test waves from the northwest.

35. Wave-runup measurements with Plan 1 installed are presented in Plates 56-79. In general, the highest runup occurred at and/or slightly north of El Morro point. Observations revealed that wave runup did not overtop the proposed revetment, and only very small quantities of water (spray) splashed into the Floating Battery.

36. Wave-induced current patterns and magnitudes secured for Plan 1 are shown in Photos 19-36. Maximum velocities obtained were 10.8, 11.5, and 6.2 fps at the shoreline north of El Morro, the area around the point, and the shoreline west of El Morro, respectively. Typical wave patterns obtained with Plan 1 installed also are shown in Photos 19-36.

37. Results of wave-height tests from the north with Plan 2 installed in the model are presented in Table 11. The maximum wave height obtained at El Morro point was 23.0 ft (gage 9) for 13-sec, 9-ft test waves; and the maximum wave height obtained west of El Morro was 10.8 ft (gage 6) for 17-sec, 12-ft test waves.

38. Wave-runup measurements obtained for test waves from the north for Plans 2 and 2A are shown in Plates 80-88. Maximum runup values of 18 ft and 20 ft occurred at El Morro point for Plans 2 and 2A, respectively, for 19-sec, 8-ft test waves. Most wave conditions for both

plans resulted in substantial runup against the exposed cliffs at El Morro. Wave-runup values for Plan 2A were similar to and, in some cases, greater than those obtained for Plan 2.

39. Wave runup secured for Plans 2B-2E are presented in Plates 89 and 90. Maximum wave runup at El Morro point ranged from 8 to 10 ft for Plan 2B, from 7 to 8 ft for Plans 2C and 2D, and from 7 to 10 ft for Plan 2E.

40. Wave-runup data obtained for Plans 2F and 2G are shown in Plates 91 and 92. Maximum wave runup at the point ranged from 5.5 to 6.5 ft for Plan 2F and from 5.5 to 8 ft for Plan 2G. A typical wave pattern for Plan 2G is shown in Photo 37.

41. None of the test plans in the Plan 2 series (Plans 2-2G) met the original runup criterion of 5 ft. To meet this criterion, either the breakwater must be raised or a revetment installed along the shoreline.

42. Results of wave-runup tests with Plans 3-3C installed in the model are presented in Plates 93-96. Maximum runup at El Morro point ranged from 14 to 15 ft for Plan 3, from 7 to 9 ft for Plan 3A, from 4 to 6 ft for Plan 3B, and from 5 to 6 ft for Plan 3C.

43. Runup data obtained for Plans 3-3C were averaged at selected gage locations (north face of El Morro, El Morro point, and west face of El Morro) and curves of runup versus breakwater crest elevation are shown in Plate 97. Based on these curves, it was determined that a breakwater crest elevation of about 6 ft was required to maintain an average wave runup of 5 ft along the shoreline north of El Morro and at El Morro point.

44. Wave-runup measurements obtained for Plan 3D are shown in Plates 98 and 99. Maximum runup at the point ranged from 5 to 6 ft. Average runup, however, was 4.7 ft at the shoreline north of El Morro and 4.6 ft at El Morro point. A typical wave pattern secured for Plan 3D is shown in Photo 38.

45. Results of wave-runup tests for Plans 4-4B are presented in Plates 100 and 101. Maximum runup at El Morro point ranged from 9 to 11 ft for Plan 4 and from 7 to 8 ft for Plans 4A and 4B.

46. Wave-runup data obtained for Plans 4-4B were averaged at gage

locations in the lee of the breakwater (gages 4-7) and runup versus breakwater crest elevation plotted as was done for Plans 3-3C. These curves (Plate 102) indicate that an average runup of 5.7 ft will occur on the north side of El Morro for the maximum crest elevation tested (8 ft, Plan 4B). Erosion should not occur for either Plan 4, 4A, or 4B since the 15-ft revetment installed along the shoreline was not overtopped, preventing the exposure of the cliff face to direct wave attack. A typical wave pattern for Plan 4 is shown in Photo 39.

47. Results of wave-runup tests with Plans 5-5B installed are presented in Plates 103 and 104. Maximum runup at the point ranged from 10 to 12 ft for Plan 5, from 6 to 10 ft for Plan 5A, and from 4 to 5 ft for Plan 5B.

48. Wave-runup data secured for Plans 5-5B were averaged at selected locations and curves of wave runup versus breakwater crest elevation were plotted as shown in Plate 105. Based on these data, a 5.5-ft breakwater crest elevation was required to maintain an average wave-runup value of 5 ft along the shoreline north of El Morro and around the point.

49. Wave-runup measurements obtained for Plan 5C are shown in Plates 106 and 107. Maximum wave runup at El Morro point ranged from 5 to 6.5 ft. Average runup, however, was 3.6 ft north of El Morro and 5.2 ft around the point. A typical wave pattern for Plan 5C is shown in Photo 40.

50. Results of wave-runup tests with Plans 6-6B installed for test waves from the north are shown in Plates 108 and 109. Maximum runup at El Morro point ranged from 11 to 15 ft for Plan 6, from 8 to 13 ft for Plan 6A, and from 4.5 to 7.5 ft for Plan 6B.

51. Wave-runup data for Plans 6-6B were averaged at selected locations and curves of runup versus breakwater crest elevation were plotted and are shown in Plate 110. Based on these curves, a breakwater crest elevation of 8 ft (Plan 6B) was required to maintain an average runup value of 5 ft around El Morro point.

52. Wave-runup data obtained for Plan 6B for test waves from the northwest are presented in Plates 111 and 112. Maximum runup at El Morro

point ranged from 4 to 8 ft. Average runup, however, was 5.5 ft around the point. A typical wave pattern for Plan 6B is shown in Photo 41.

53. Results of wave-runup tests for Plans 7-7B for representative test waves from the northwest and north, and Plans 7A and 7B for test waves from the northeast, are shown in Plates 113-128. Maximum wave runup at El Morro point ranged from 11 to 25 ft for Plan 7, from 4 to 12 ft for Plan 7A, and from 4 to 11 ft for Plan 7B.

54. Wave-induced current patterns and magnitudes secured for Plans 7A and 7B are shown in Photos 42-83. Each plan resulted in maximum velocities of 11.5 fps seaward of the offshore breakwater and 7.9 fps between the breakwater and revetment. Typical wave patterns obtained with Plans 7A and 7B installed also are shown in Photos 42-83.

55. Results of wave-runup tests with Plan 7A installed for the remaining test conditions not discussed in paragraph 53 are shown in Plates 129-144. Maximum wave runup at El Morro point ranged from 3 to 12 ft for these waves.

56. Wave-height tests conducted for Plan 7A are presented in Tables 12-14. The maximum wave height obtained north of El Morro was 21.8 ft (gage 47) for 9-sec, 16-ft test waves from the north; and the maximum wave height obtained west of El Morro was 11.3 ft (gage 43) for 11-sec, 12-ft test waves from northwest.

57. Additional wave-height tests conducted for Plan 7A, monitoring wave heights between the breakwater and the revetment, are presented in Table 15. The maximum wave height obtained behind the breakwater was 8.6 ft (gage 55) for 15-sec, 18-ft test waves from north.

58. Wave-runup data obtained for Plans 7C and 7D are presented in Plates 145-170 for test waves from the northwest, north, and northeast. For comparison purposes, wave-runup data secured for Plan 7A also are plotted in Plates 145-170. Maximum wave runup at El Morro point ranged from 3 to 15 ft for both Plans 7C and 7D. Typical wave patterns obtained for Plans 7C and 7D are shown in Photos 84-89.

Discussion of test results

59. Test results obtained for existing conditions revealed rough and turbulent wave conditions along the historic site north of El Morro,

around El Morro point, and west of El Morro. Wave heights in excess of 24 ft were obtained around the point and in the vicinity of the proposed breakwaters; wave runup up to 30 ft was observed along the north side of El Morro and around the point; and current magnitudes as high as 13 fps were recorded north of El Morro.

60. Test results for Plan 1 indicated that the revetment appeared to be well designed. Wave runup was not high enough to cause problems since it did not overtop the revetment, yet was high enough that the 15-ft crest elevation could not be lowered. Wave-height and current measurements, model photographs and motion picture footage, and visual observations revealed no problems with this plan; and the photographs, motion pictures, and visual observations, in particular, indicate considerably calmer conditions in the vicinity of El Morro Castle.

61. Test results secured for the Plan 2 series (Plans 2-2G) indicate that none of these plans met the original wave-runup criterion of 5 ft. To meet this criterion, either the crest elevation of the breakwater must be raised or a revetment installed along the shoreline.

62. Test results for the Plan 3 series (Plans 3-3D) revealed that a breakwater crest elevation of 6 ft (Plan 3D) was required so that the original runup criterion of 5 ft would not be exceeded. Average runup obtained north of El Morro and around the point for Plan 3D were 4.7 and 4.6 ft, respectively.

63. Results of runup tests for the Plan 4 series (Plans 4-4B) indicated that an average runup of 5.7 ft will occur in the lee of the breakwater for the maximum crest elevation tested (8 ft, Plan 4B). Erosion should not occur, however, since the revetment along the shoreline was not overtopped. As a cost saving measure the revetment elevation for the Plan 4 series could be reduced in the lee of the breakwater based on the maximum runup obtained.

64. Test results for Plans 5-5C revealed that a 5.5-ft breakwater crest elevation (Plan 5C) was required to reduce the average runup around El Morro point to 5.2 ft. Average runup north of El Morro was reduced to 3.6 ft for this test plan.

65. Test results for Plans 6-6B indicated that an 8-ft breakwater

crest elevation (Plan 6B) was required to maintain an average runup of 5 ft around El Morro point for test waves from the north. For waves from the northwest, however, Plan 6B yielded average wave runup of 5.5 ft at El Morro point.

66. Results of wave-runup tests for Plans 7-7B revealed that both Plans 7A and 7B would effectively reduce wave runup at the point and north shore of El Morro to an acceptable level considering the new runup criterion of 10 ft in the area for these plans. Even though some test waves resulted in runup of 11 or 12 ft, at isolated locations the waves producing this runup are very infrequent. A comparison of wave-induced current patterns and magnitudes for Plans 7A and 7B also revealed similar results for both plans.

67. A comparison of wave runup obtained for Plans 7A, 7C, and 7D (Plates 145-170) reveals that the runup criterion of 10 ft at El Morro point was exceeded by 6 test waves for Plan 7A, 10 test waves for Plan 7C, and 11 test waves for Plan 7D. Maximum runup at the point was 12 ft for Plan 7A and 15 ft for Plans 7C and 7D. These data also revealed that the removal of 161 ft of structure from the eastern end of the offshore breakwater (Plan 7D) resulted in wave runup within the established criteria at the shoreline in this area.

68. To show the effectiveness of the Plan 7A breakwater and revetments in regard to wave runup at El Morro, curves depicting runup for existing conditions and Plan 7A are presented in Plates 171-185 for representative test waves from the northwest, north, and northeast. A comparison of wave-induced current magnitudes obtained for existing conditions and Plan 7A reveals maximum velocities of 13.2 and 11.5 fps, respectively, north of El Morro.

69. To aid SAJ in the selection of an improvement plan with regard to cost considerations, the amount of rock required for the construction of each test plan is shown in Table 16.

PART V: CONCLUSIONS

70. Based on the results of the hydraulic model investigation reported herein, it is concluded that:

a. Existing conditions are characterized by very rough and turbulent wave conditions along the San Juan National Historic Site during periods of moderate to large wave attack.

b. Tests involving the revetment plan (Plan 1) indicated that a 15-ft-high revetment was the optimum with respect to wave runup data obtained (i.e. maximum runup came to the top of the revetment but did not overtop in most cases).

c. Of the improvement plans involving a shore-connected breakwater (Plans 2-2G), it was determined that increasing the width or raising the seaward edge of the breakwater, to achieve the wave-runup criteria, would require a significantly larger volume of rock than would the other plans tested (see Table 16).

d. Of the improvement plans involving an offshore breakwater north of El Morro and around El Morro point (Plans 3-3D), it was determined that at least a 6-ft breakwater crest elevation (Plan 3D) was required to maintain an average runup value at the shoreline of less than 5 ft (original runup criterion).

e. Of the improvement plans involving a 15-ft-high revetment and a breakwater north of El Morro (Plans 4-4B), it was determined that the revetment elevation could be reduced in the lee of the breakwater based on the maximum runup obtained for the corresponding plan.

f. Of the improvement plans involving an offshore breakwater north of El Morro and around the point with a transition to a 15-ft-high west shore revetment (Plans 5-5C), it was determined that a 5.5-ft breakwater crest elevation (Plan 5C) resulted in average runup at the point of 5.2 ft (slightly above the original 5.0-ft criterion).

g. Of the improvement plans involving an offshore breakwater extending around the point and to the west and north of El Morro with no revetment (Plans 6-6B), it was determined that an 8-ft breakwater crest elevation (Plan 6B) would most nearly meet the desired criterion of 5.0 ft (average wave runup was 5.5 ft at the point).

h. Of the improvement plans involving an offshore breakwater in conjunction with a revetment at the shoreline north of El Morro and around the point and a west shore revetment (Plans 7A-7D), it was determined that either Plan 7A or 7B

would be effective in reducing wave runup to an acceptable level (considering the revised wave-runup criterion of 10 ft north of El Morro and westward around the point).

i. The removal of 161 ft of structure from the eastern end of the offshore breakwater (Plan 7D) will result in wave runup within the revised criterion (12 ft) at the shoreline behind the removed structure.

j. The installation of any of the major improvement plans tested should have no adverse effect on waves in the entrance to San Juan Bay or currents around El Morro Castle.

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Table 1

Shipboard Observations of Deepwater Waves (Sea and Swell) Approaching San Juan National Historic Site from Various Directions

Wave Height ft	Total Observations* per Wave Period, sec 5	7	9	11	13	15	17	>19	Total
Northwest (295°-335°)									
0- 3.3	168	18	6	2	2	--	--	6	202
3.3- 6.6	98	62	35	16	5	5	1	--	222
6.6- 9.8	15	9	19	3	2	2	--	--	50
9.8-13.1	1	2	7	6	1	--	--	--	17
13.1-16.4	--	1	1	--	2	--	--	--	4
16.4-19.7	--	--	2	--	--	--	--	--	2
Total	282	92	70	27	12	7	1	6	497
North (335°-25°)									
0- 3.3	565	45	13	5	9	3	--	3	643
3.3- 6.6	440	275	104	53	15	13	1	2	903
6.6- 9.8	60	111	102	36	21	12	1	--	343
9.8-13.1	9	27	33	18	7	2	--	--	96
13.1-16.4	--	7	7	3	5	1	--	--	23
16.4-19.7	2	--	1	--	--	1	--	--	4
19.7-23.0	1	--	2	1	--	1	--	--	5
Total	1077	465	262	116	57	33	2	5	2017
Northeast (25°-75°)									
0- 3.3	2924	183	55	17	15	11	--	31	3236
3.3- 6.6	3408	1195	280	72	44	26	2	11	5038
6.6- 9.8	426	543	267	82	22	16	1	1	1358
9.8-13.1	48	64	83	32	15	4	--	--	246
13.1-16.4	5	17	13	7	2	--	1	--	45
16.4-19.7	3	--	4	2	--	--	--	--	9
19.7-23.0	--	--	--	1	--	--	--	--	1
23.0-26.2	--	1	--	--	--	--	--	--	1
Total	6814	2003	702	213	98	57	4	43	9934

* Based on total of 34,986 observations from 1949-1975.

Table 2

Estimated Shallow-Water Waves (Sea and Swell) Approaching San Juan Historic Site from the Various Directions

Wave Height ft	Total Observations* per Wave Period, sec 5	7	9	11	13	15	17	>19	Total
					Northwest				
2- 4	168	18	6	2	2	--	--	6	202
4- 6	--	62	35	16	5	--	--	--	118
6- 8	98	--	--	--	--	5	1	--	104
8-10	15	9	19	3	2	2	--	--	50
10-12	--	2	7	6	1	--	--	--	16
12-14	1	--	1	--	--	--	--	--	2
14-16	--	1	2	--	2	--	--	--	5
Total	282	92	70	27	12	7	1	6	497
					North				
2- 4	565	45	13	5	9	3	--	3	643
4- 6	--	--	--	--	--	--	--	--	--
6- 8	440	275	104	53	15	13	1	2	903
8-10	60	111	102	36	--	--	--	--	309
10-12	--	--	33	--	21	12	1	--	67
12-14	9	27	--	18	7	--	--	--	61
14-16	--	7	7	3	--	2	--	--	19
16-18	2	--	--	--	5	1	--	--	8
18-20	--	--	1	--	--	--	--	--	1
20-22	1	--	2	1	--	2	--	--	6
Total	1077	465	262	116	57	33	2	5	2017
					Northeast				
2- 4	2924	183	55	17	15	11	--	31	3236
4- 6	--	--	280	--	--	--	--	--	280
6- 8	3408	1195	--	72	44	26	2	11	4758
8-10	426	543	267	82	22	--	--	--	1340
10-12	--	--	83	--	--	16	1	1	101
12-14	48	64	--	32	15	4	--	--	163
14-16	5	17	13	7	--	--	--	--	42
16-18	--	--	4	--	2	--	1	--	7
18-20	3	--	--	2	--	--	--	--	5
20-22	--	--	--	1	--	--	--	--	1
22-24	--	--	--	--	--	--	--	--	--
24-26	--	1	--	--	--	--	--	--	1
Total	6814	2003	702	213	98	57	4	43	9934

* Based on a total of 34,986 observations from 1949-1975.

Table 3

Wave Heights for Existing Conditions (Gages 1-20)

with Test Waves from Northwest and North

Test Wave			Wave Height, ft									
Direction	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
Northwest	5.0	6.0	1.9	0.7	3.9	2.3	3.3	3.9	7.0	3.6	7.2	5.5
		12.0	5.8	1.4	3.1	3.7	2.7	7.5	8.6	8.0	15.9	10.4
	7.0	8.0	1.6	1.4	2.4	3.0	1.5	7.3	6.7	7.0	10.7	7.9
		16.0	6.1	4.6	4.8	5.8	4.1	12.4	8.8	12.2	15.3	15.1
	9.0	8.0	6.9	1.3	2.0	2.3	4.4	5.4	12.7	6.2	7.8	6.5
		16.0	6.8	6.6	7.3	6.2	8.1	12.3	10.1	10.1	8.9	13.6
	11.0	6.0	4.8	1.0	1.6	2.2	5.0	6.9	6.1	5.4	9.6	10.2
		12.0	5.5	3.3	7.4	5.9	7.9	11.0	8.8	13.2	11.3	19.7
	13.0	8.0	4.0	1.0	3.2	3.5	7.3	7.0	8.4	8.4	16.6	14.1
		16.0	6.0	6.7	8.1	6.7	7.0	13.9	8.1	14.3	13.0	19.3
	15.0	6.0	3.0	1.4	3.5	3.8	6.9	6.1	7.7	9.5	8.8	8.7
		10.0	4.2	2.0	8.6	4.6	8.4	9.8	8.0	11.0	14.3	17.7
	17.0	4.0	1.9	1.8	2.0	1.2	4.3	2.7	3.7	4.7	5.8	5.7
		8.0	2.4	1.2	3.6	5.3	8.1	5.7	8.0	7.7	14.2	9.7
	19.0	4.0	2.2	1.7	1.9	3.7	5.8	3.9	1.6	3.1	6.0	5.5
North	5.0	6.0	0.5	0.1	1.9	1.1	2.3	3.1	6.0	5.4	6.7	5.7
		12.0	4.6	1.2	2.4	2.5	2.5	4.8	5.8	6.6	12.9	10.6
	7.0	8.0	5.6	1.0	1.6	2.0	1.9	10.0	8.0	7.4	9.8	9.5
		16.0	5.3	3.8	4.3	3.2	4.0	6.9	8.0	7.9	9.6	18.7
	9.0	8.0	4.9	2.0	2.4	1.5	4.2	5.1	7.7	12.2	11.5	9.3
		16.0	5.3	2.6	5.3	4.2	6.5	8.6	7.6	6.0	12.6	19.0
		22.0	7.1	2.6	6.1	5.1	7.4	10.0	10.2	9.3	11.6	17.3
	11.0	8.0	4.5	1.5	4.0	3.8	7.9	7.5	7.5	10.1	16.5	16.8
		16.0	4.3	2.2	4.0	4.2	4.2	7.3	7.3	7.9	9.9	16.1
	13.0	9.0	5.0	2.4	7.9	5.1	8.0	9.4	7.6	9.7	17.5	15.6
		18.0	5.0	5.5	6.8	5.5	7.4	10.4	8.8	10.8	13.8	17.0
	15.0	9.0	3.7	1.9	6.4	3.9	6.6	6.9	7.6	8.1	17.4	16.6
		18.0	4.3	3.1	6.6	4.8	6.5	5.9	8.9	11.1	12.5	20.7
	17.0	6.0	1.7	1.0	2.3	2.8	7.3	4.6	10.6	10.2	15.3	9.5
		12.0	5.6	3.7	8.9	5.8	8.0	9.7	8.0	8.4	11.1	19.7
	19.0	4.0	2.5	1.2	1.9	2.6	4.6	3.0	6.6	4.6	8.2	7.5
		8.0	6.1	4.0	6.6	3.6	7.5	9.2	7.9	11.8	21.2	15.3

(Continued)

Table 3 (Concluded)

Test Wave			Wave Height, ft									
Direction	Period sec	Height ft	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17	Gage 18	Gage 19	Gage 20
Northwest	5.0	6.0	7.7	3.0	5.9	7.8	4.8	6.7	6.8	8.1	5.2	3.4
		12.0	13.7	6.7	8.8	8.2	10.2	11.2	13.8	8.9	4.6	3.3
	7.0	8.0	10.7	10.8	10.5	9.3	13.1	5.8	5.8	9.3	5.0	3.6
		16.0	13.8	5.9	9.4	9.4	14.1	13.4	14.5	8.5	6.3	3.5
	9.0	8.0	10.4	8.6	9.0	6.2	7.8	5.1	5.2	5.6	4.9	4.1
		16.0	11.1	13.3	7.0	7.6	6.9	20.0	15.2	5.8	5.5	4.6
	11.0	6.0	9.6	11.1	10.8	7.0	8.6	3.3	7.0	5.1	4.9	4.8
		12.0	14.0	12.7	11.4	9.0	10.8	11.1	12.2	5.9	5.7	4.4
	13.0	8.0	13.8	11.1	8.6	9.4	12.1	6.8	6.4	6.0	4.1	4.1
		16.0	17.0	13.3	12.4	8.4	10.3	19.6	17.2	6.4	4.9	4.0
	15.0	6.0	10.3	7.8	11.2	9.2	8.8	5.6	5.1	5.3	4.8	4.1
		10.0	16.1	10.1	9.5	9.7	9.3	6.8	7.6	5.8	4.4	4.2
	17.0	4.0	6.8	7.5	10.6	4.8	6.1	2.8	4.0	6.6	4.2	4.3
		8.0	19.0	13.9	10.6	9.0	11.1	6.7	7.6	6.2	4.7	4.2
	19.0	4.0	7.0	6.1	10.8	4.8	6.6	3.8	3.3	6.9	3.6	3.9
North	5.0	6.0	4.4	8.9	9.2	4.0	2.8	6.1	6.5	6.5	3.5	3.3
		12.0	11.5	9.3	10.8	6.4	12.9	10.1	12.8	5.7	4.2	4.0
	7.0	8.0	11.7	15.6	10.6	8.1	11.3	5.3	7.1	7.8	4.6	3.8
		16.0	11.2	10.3	8.6	8.7	14.3	8.3	12.9	7.4	4.7	5.3
	9.0	8.0	6.4	12.7	8.9	7.1	9.8	5.0	5.4	6.9	4.1	5.2
		16.0	17.4	10.0	7.3	7.1	15.0	13.1	15.5	6.3	4.6	4.9
		22.0	11.0	9.9	7.9	7.2	13.6	19.3	21.3	5.9	5.5	4.2
	11.0	8.0	8.7	11.1	7.1	6.6	8.5	4.9	6.4	5.2	4.7	4.9
		16.0	15.6	8.3	7.7	9.4	14.3	11.2	14.7	5.7	4.6	4.7
	13.0	9.0	14.1	14.3	10.5	9.0	15.9	6.4	8.6	5.4	3.9	4.1
		18.0	16.2	10.9	9.9	7.6	12.3	20.1	24.2	6.2	4.5	5.0
	15.0	9.0	19.6	16.2	12.5	7.5	0.7	4.8	7.2	5.6	3.4	3.9
		18.0	24.4	13.5	10.8	6.8	15.4	14.1	16.0	5.2	4.8	4.7
	17.0	6.0	12.5	13.2	7.1	7.2	9.5	4.4	4.8	6.4	4.3	3.5
		12.0	20.8	11.5	8.2	5.7	11.2	6.5	10.1	5.1	5.7	4.2
	19.0	4.0	6.5	15.4	10.4	8.5	7.3	2.7	4.1	5.5	4.1	4.2
		8.0	14.0	14.6	8.5	7.2	16.6	4.6	7.1	5.5	3.2	5.3

Table 4

Wave Heights for Existing Conditions (Gages 1-20)

with Test Waves from Northeast

Test Wave		Wave Height, ft									
Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10
5.0	6.0	2.5	0.2	0.9	0.6	0.8	0.9	1.4	1.4	4.8	5.5
	12.0	2.5	0.9	2.7	2.2	1.8	4.3	4.8	3.5	6.6	8.5
7.0	8.0	2.0	1.6	1.6	1.5	1.3	2.7	4.5	4.0	9.0	7.8
	16.0	4.9	3.6	3.9	3.0	2.9	3.9	5.5	5.2	10.7	17.2
9.0	9.0	5.6	1.3	4.3	1.3	2.7	4.9	8.6	6.9	7.5	10.0
	18.0	4.8	2.3	7.4	5.0	5.3	8.5	7.6	5.3	9.7	18.0
11.0	10.0	5.0	3.1	2.9	4.0	5.0	5.4	10.4	8.5	11.4	19.6
	22.0	6.2	4.0	7.4	5.4	7.9	12.0	7.9	7.4	13.6	17.6
13.0	9.0	5.0	4.2	7.5	6.8	5.3	6.8	8.4	8.4	16.4	17.6
	18.0	5.8	5.0	9.2	5.1	7.4	9.4	8.9	8.8	14.3	20.3
15.0	7.0	5.9	3.5	8.7	5.7	6.2	9.3	7.8	14.1	12.0	14.5
	14.0	5.9	4.3	9.9	6.2	8.1	12.4	9.2	10.8	17.4	21.3
17.0	6.0	6.1	3.5	8.0	5.6	6.7	9.2	11.1	10.6	10.2	14.1
	12.0	5.2	4.1	9.4	6.5	6.6	7.9	8.9	11.9	15.8	20.7
19.0	6.0	5.9	5.8	5.5	3.6	8.6	7.6	6.5	9.6	10.6	10.9
	11.0	5.8	5.2	8.4	6.4	9.8	10.2	8.5	7.7	14.6	18.2
9.0	29.0	5.6	3.2	8.2	3.9	5.5	7.9	12.7	9.2	16.5	16.6

(Continued)

Table 4 (Concluded)

Test Wave		Wave Height, ft									
Period sec	Height ft	Gage 11	Gage 12	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17	Gage 18	Gage 19	Gage 20
5.0	6.0	2.4	5.5	9.1	0.9	5.7	6.3	5.0	6.0	2.4	4.2
	12.0	10.1	9.6	10.6	3.9	8.5	11.8	12.7	6.9	4.3	4.2
7.0	8.0	10.9	14.2	11.6	4.4	18.1	7.8	6.3	8.6	4.6	4.2
	16.0	18.3	11.2	11.9	4.9	8.9	18.8	13.6	7.4	4.9	5.8
9.0	9.0	11.7	13.1	10.2	5.7	14.0	6.2	5.6	6.8	4.0	5.1
	18.0	10.4	7.8	7.9	6.0	9.4	21.6	20.0	7.2	5.5	5.3
11.0	10.0	13.9	8.9	6.9	9.0	11.0	11.3	7.0	5.8	4.8	4.4
	22.0	15.4	9.3	10.4	9.0	10.0	17.5	18.8	6.4	7.1	5.2
13.0	9.0	18.6	10.3	10.0	6.5	11.1	7.8	6.4	6.7	4.8	4.2
	18.0	12.5	11.4	10.2	5.8	11.8	17.4	14.9	7.6	5.1	4.5
15.0	7.0	17.5	12.5	11.7	7.0	14.8	3.9	4.4	5.7	5.0	5.0
	14.0	21.7	11.6	16.1	5.3	12.3	12.1	10.7	6.8	5.1	3.7
17.0	6.0	9.0	15.3	8.7	7.6	13.4	2.0	3.9	7.1	4.8	4.3
	12.0	16.0	12.3	12.5	8.1	11.1	15.1	9.8	7.4	4.5	3.1
19.0	6.0	10.8	13.0	7.1	6.3	9.3	4.4	4.3	5.4	5.4	4.4
	11.0	16.3	12.8	8.4	5.7	11.2	14.7	11.3	7.3	5.4	6.4
9.0	29.0	13.7	10.8	8.5	9.4	11.1	16.6	19.1	7.4	6.2	6.6

Table 5

Wave Heights for Existing Conditions (Gages 21-29)

with Test Waves from Northeast

Test Wave		Wave Height, ft								
Period sec	Height ft	Gage 21	Gage 22	Gage 23	Gage 24	Gage 25	Gage 26	Gage 27	Gage 28	Gage 29
5.0	6.0	3.4	4.0	3.7	3.2	1.1	5.1	7.2	8.4	5.6
	12.0	4.1	4.4	4.1	3.4	1.1	6.8	8.7	9.5	7.2
7.0	8.0	3.6	4.0	5.0	3.7		5.5	9.3	9.0	10.3
	16.0	4.7	6.5	5.5	5.0	1.8	6.3	6.4	7.1	8.9
9.0	9.0	3.9	4.3	5.4	3.6	2.2	5.8	10.7	8.8	8.0
	18.0	5.7	5.8	8.0	4.9	2.0	7.4	8.8	9.9	9.1
11.0	10.0	4.4	3.9	5.1	3.9	2.1	4.8	10.2	9.0	8.2
	22.0	4.5	4.8	5.5	4.9	2.6	10.7	8.3	9.0	8.8
13.0	9.0	4.3	4.5	5.2	4.5	2.3	5.4	8.5	9.6	7.2
	18.0	4.6	4.6	5.4	4.5	2.3	8.4	8.6	8.6	7.8
15.0	7.0	4.7	4.5	6.1	4.3	2.0	7.0	10.7	9.3	8.3
	14.0	4.1	4.3	4.9	4.1	1.9	6.9	8.5	7.5	10.0
17.0	6.0	4.8	4.3	5.0	4.0	2.3	4.9	9.3	10.2	9.2
	12.0	4.8	4.0	4.4	3.8	2.1	7.1	8.8	8.6	9.0
19.0	6.0	3.8	4.3	5.2	4.3	3.1	6.1	9.7	9.3	7.0
	11.0	4.8	5.1	5.5	5.4	2.5	5.0	8.6	8.2	7.6

Table 6

Wave Heights for Existing Conditions (Gages 30-39)

with Test Waves from Northwest and North

Test Wave			Wave Height, ft									
Direction	Period sec	Height ft	Gage 30	Gage 31	Gage 32	Gage 33	Gage 34	Gage 35	Gage 36	Gage 37	Gage 38	Gage 39
Northwest	5.0	6.0	6.2	4.1	5.2	4.6	5.4	5.3	7.2	7.9	6.0	7.1
		12.0	5.6	4.2	5.1	5.1	5.5	5.5	8.1	9.3	7.9	8.8
	7.0	8.0	4.6	4.5	6.0	5.3	8.3	6.0	11.2	12.7	10.4	7.9
		16.0	7.3	5.3	6.2	6.7	6.4	6.2	8.9	10.4	9.5	9.0
	9.0	8.0	4.5	5.1	5.8	5.6	8.7	7.7	12.7	9.6	9.6	9.2
		16.0	7.4	5.4	7.0	6.0	9.1	8.6	10.1	8.5	9.4	9.8
	11.0	6.0	5.9	6.1	6.1	6.0	9.3	8.5	10.3	8.9	9.8	12.9
		12.0	5.3	5.0	5.8	5.0	5.4	5.9	8.3	9.3	10.8	9.3
	13.0	8.0	5.7	6.1	7.2	5.6	6.3	5.2	8.9	11.4	14.5	11.9
		16.0	6.7	5.3	8.0	5.5	7.5	8.1	9.8	10.8	12.0	9.9
	15.0	6.0	6.4	4.8	7.5	5.8	6.0	10.5	9.9	14.3	16.7	14.9
		10.0	6.4	4.7	6.8	5.6	5.4	8.4	9.3	10.6	11.5	11.3
	17.0	4.0	5.8	5.8	7.5	5.5	7.7	8.1	10.1	8.9	9.2	7.8
		8.0	6.0	5.1	5.8	5.7	5.6	6.4	9.2	8.3	9.9	9.5
	19.0	4.0	6.1	5.2	6.9	6.2	8.4	5.7	12.7	10.1	12.3	9.8
North	5.0	6.0	4.6	5.0	5.5	4.2	5.1	4.9	6.9	4.2	4.7	3.1
		8.0	4.8	4.8	5.5	4.2	4.9	3.6	6.6	5.3	7.2	7.3
	7.0	8.0	8.2	4.9	6.1	5.1	5.5	5.3	9.8	11.2	8.1	3.5
		16.0	6.6	5.8	6.7	5.9	7.3	6.1	9.8	6.6	7.0	8.0
	9.0	8.0	7.4	4.5	9.0	5.3	5.2	6.8	10.0	9.8	8.7	6.5
		16.0	6.2	6.3	6.4	5.4	7.3	6.9	9.8	8.0	9.7	7.8
		22.0	6.9	8.3	10.7	6.5	8.7	9.3	13.6	9.6	10.1	9.4
	11.0	8.0	5.6	5.3	6.9	5.9	7.9	5.5	9.8	11.5	10.3	9.3
		16.0	6.7	5.5	7.5	5.3	9.4	7.9	7.3	9.3	8.6	10.8
	13.0	9.0	5.3	7.1	9.4	7.7	5.6	8.2	10.9	14.8	10.2	9.4
		18.0	6.2	5.8	8.3	7.3	7.0	10.9	10.6	12.0	9.9	8.5
	15.0	9.0	5.5	5.4	5.9	5.4	7.2	7.7	8.3	12.8	10.7	10.5
		18.0	6.4	5.3	6.8	6.2	8.8	7.4	9.8	11.0	11.4	9.8
	17.0	6.0	8.6	6.0	5.4	5.7	7.2	6.1	8.4	11.6	8.5	8.1
		12.0	7.4	5.1	6.2	5.3	8.2	7.0	10.2	12.6	9.9	8.5
	19.0	4.0	7.3	5.4	8.7	5.5	6.2	7.2	10.9	7.4	4.8	3.3
		8.0	6.3	5.4	6.7	5.3	5.6	10.0	10.2	12.0	9.5	11.7

Table 7

Wave Heights for Existing Conditions (Gages 30-39)

with Test Waves from Northeast

Test Wave		Wave Height, ft									
Period sec	Height ft	Gage 30	Gage 31	Gage 32	Gage 33	Gage 34	Gage 35	Gage 36	Gage 37	Gage 38	Gage 39
5.0	6.0	7.2	3.8	6.0	4.2	5.1	4.9	4.7	10.0	6.3	6.8
	12.0	7.0	4.6	5.4	4.0	5.0	5.3	7.7	11.2	8.9	8.3
7.0	8.0	10.8	5.2	5.6	4.1	5.6	7.0	9.4	9.1	12.3	9.6
	16.0	13.7	5.7	6.3	5.3	6.9	5.3	10.0	7.7	9.9	6.8
9.0	9.0	9.6	4.7	5.4	5.3	5.9	5.4	10.4	10.5	9.9	7.1
	18.0	8.7	6.6	7.2	5.6	7.2	8.5	10.1	10.0	7.0	9.2
11.0	10.0	7.8	6.0	6.2	5.5	5.8	5.4	8.3	11.5	10.2	9.2
	22.0	7.0	7.5	6.6	5.9	9.5	6.7	7.6	9.4	11.7	8.8
13.0	9.0	8.4	6.5	6.6	5.8	6.7	5.9	10.6	14.9	12.1	9.8
	18.0	8.1	5.7	6.5	5.5	7.4	7.6	10.5	12.2	12.3	8.6
15.0	7.0	6.0	8.4	8.2	7.2	6.7	5.6	13.8	13.5	12.6	12.5
	14.0	9.8	5.4	6.2	7.0	6.1	6.8	9.4	11.1	14.0	11.0
17.0	6.0	7.9	5.7	7.7	4.5	5.9	6.0	14.8	9.8	9.2	8.9
	12.0	7.8	7.7	6.2	5.3	6.1	6.8	12.0	9.2	8.7	7.9
19.0	6.0	6.5	5.4	6.6	6.1	5.2	8.5	12.2	9.7	9.9	8.5
	11.0	8.4	5.9	6.6	6.1	5.7	6.6	7.2	9.1	10.3	7.7

Table 8

Water Depths and Maximum Wave Heights Obtained for Existing Conditions at the Various Gage Locations

Gage No.	Water Depth,* ft	Maximum Wave Height, ft	Wave Condition, Direction
1	7.9	7.1	9-sec, 22-ft waves, North
2	9.0	6.7	13-sec, 16-ft waves, Northwest
3	11.6	9.9	15-sec, 14-ft waves, Northeast
4	9.9	6.8	13-sec, 9-ft waves, Northeast
5	11.4	9.8	19-sec, 11-ft waves, Northeast
6	18.8	13.9	13-sec, 16-ft waves, Northwest
7	10.4	12.7	9-sec, 8-ft waves, Northwest
8	21.0	14.3	13-sec, 16-ft waves, Northwest
9	21.9	21.2	19-sec, 8-ft waves, North
10	23.1	21.3	15-sec, 14-ft waves, Northeast
11	22.9	24.4	15-sec, 18-ft waves, North
12	20.6	16.2	15-sec, 9-ft waves, North
13	13.4	16.1	15-sec, 14-ft waves, Northeast
14	12.0	9.7	15-sec, 10-ft waves, Northwest
15	20.2	18.1	7-sec, 8-ft waves, Northeast
16	55.6	21.6	9-sec, 18-ft waves, Northeast
17	51.4	24.2	13-sec, 18-ft waves, North
18	12.7	9.3	7-sec, 8-ft waves, Northwest
19	6.5	7.1	11-sec, 22-ft waves, Northeast
20	10.8	6.4	19-sec, 11-ft waves, Northeast
21	6.1	5.7	9-sec, 18-ft waves, Northeast
22	6.8	6.5	7-sec, 16-ft waves, Northeast
23	4.7	8.0	9-sec, 18-ft waves, Northeast
24	4.5	5.4	19-sec, 11-ft waves, Northeast
25	3.2	3.1	19-sec, 6-ft waves, Northeast
26	5.8	10.7	11-sec, 22-ft waves, Northeast
27	11.2	10.7	9-sec, 9-ft waves and 15-sec, 7-ft waves, Northeast
28	11.6	10.2	17-sec, 6-ft waves, Northeast
29	12.1	10.3	7-sec, 8-ft waves, Northeast
30	11.1	13.7	7-sec, 16-ft waves, Northeast
31	7.1	8.4	15-sec, 7-ft waves, Northeast
32	7.1	10.7	9-sec, 22-ft waves, North
33	7.1	7.7	13-sec, 9-ft waves, North
34	7.1	9.5	11-sec, 22-ft waves, Northeast
35	7.1	10.5	15-sec, 6-ft waves, Northwest
36	13.1	14.8	17-sec, 6-ft waves, Northeast
37	13.1	14.8	13-sec, 9-ft waves, North
38	13.1	16.7	15-sec, 6-ft waves, Northwest
39	13.1	14.9	15-sec, 6-ft waves, Northwest

* Includes still water level of 1.1 ft above mean sea level.

Table 9

Wave Heights for Plan 1 with Test Waves from Northwest

Test Wave		Wave Height, ft									
Period sec	Height ft	Gage 5	Gage 6	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 16	Gage 17
5.0	6.0	3.7	5.7	4.3	6.2	6.1	7.3	4.9	5.6	5.3	6.8
	12.0	6.0	9.5	8.7	11.5	12.2	13.7	8.8	7.6	11.7	13.2
7.0	8.0	6.4	6.0	5.1	11.3	10.3	11.9	8.7	8.8	4.9	7.5
	16.0	8.5	10.2	9.7	16.7	17.9	13.0	8.2	8.8	15.9	14.0
9.0	8.0	7.1	5.0	4.9	11.2	9.0	9.6	8.1	10.1	5.7	6.4
	16.0	8.7	11.0	10.7	13.5	17.9	10.6	10.3	7.2	20.7	15.9
11.0	6.0	5.5	3.7	5.4	9.7	9.6	11.7	15.1	9.3	4.4	5.3
	12.0	10.9	12.6	12.1	11.6	19.9	15.5	11.7	9.7	13.0	11.7
13.0	8.0	8.5	10.9	9.4	18.0	16.8	17.6	18.0	8.3	8.0	8.4
	16.0	9.6	15.0	11.4	12.6	17.2	15.0	14.4	10.3	17.4	20.8
15.0	6.0	4.7	4.7	8.4	11.8	7.7	15.0	13.2	9.4	4.8	4.5
	10.0	7.1	8.8	10.3	17.0	14.2	17.6	14.2	9.9	6.8	7.4
17.0	4.0	2.1	2.4	3.5	7.4	5.4	7.8	6.0	10.4	2.7	3.8
	8.0	5.2	5.3	7.1	15.1	12.5	18.2	10.0	8.7	6.2	7.5
19.0	4.0	2.3	3.0	2.6	7.0	6.2	4.9	4.0	12.3	2.2	4.1

Table 10

Wave Heights for Plan 1 with Test Waves

from North and Northeast

Test Wave			Wave Height, ft									
Direction	Period sec	Height ft	Gage 5	Gage 6	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 16	Gage 17
North	5.0	6.0	1.4	3.7	3.3	7.7	5.5	4.8	6.5	6.6	5.7	6.0
		12.0	2.5	6.1	6.3	11.8	12.5	10.4	7.2	6.3	10.3	11.5
	7.0	8.0	5.0	7.3	6.2	10.2	9.1	9.2	8.8	11.6	6.0	6.4
		16.0	2.8	6.2	8.7	12.7	15.3	10.5	6.2	7.9	11.8	13.8
	9.0	8.0	3.0	1.8	8.0	11.6	10.5	8.9	11.3	8.0	3.4	6.7
		16.0	5.3	4.3	7.7	10.3	20.2	16.0	8.4	7.8	10.9	16.1
		22.0	9,6	8.2	7.8	9.8	12.4	15.0	9.0	7.7	23.6	26.0
	11.0	8.0	7.7	7.9	11.4	16.1	14.7	11.0	9.9	7.9	3.6	6.4
		16.0	4.8	5.4	7.7	11.6	19.0	16.6	8.8	8.5	13.2	13.0
	13.0	9.0	6.7	6.5	7.9	19.6	17.3	14.6	10.6	7.5	5.2	6.9
		18.0	7.9	10.0	9.5	10.8	15.4	14.5	10.0	9.0	18.9	19.2
	15.0	9.0	4.7	5.4	9.6	17.7	16.0	14.9	11.6	8.9	4.9	5.5
		18.0	8.9	9.4	9.5	12.5	17.8	12.0	12.8	8.8	18.0	11.1
	17.0	6.0	2.0	3.9	7.3	17.1	12.3	10.7	10.9	7.3	3.4	4.1
		12.0	8.7	10.4	6.9	11.4	18.2	19.3	10.3	8.4	8.6	10.1
	19.0	4.0	2.6	2.4	3.9	10.5	7.0	6.6	9.9	10.6	1.9	3.9
		8.0	7.4	5.9	12.6	22.5	13.5	15.2	10.2	9.0	5.0	8.4
Northeast	5.0	6.0	0.5	0.8	1.3	4.7	4.6	5.2	6.5	6.4	6.2	5.4
		12.0	1.9	4.7	3.1	8.9	9.7	6.7	8.0	7.3	11.8	13.9
	7.0	8.0	2.4	2.8	3.6	0.4	7.3	8.4	9.3	9.5	5.9	4.5
		16.0	2.5	5.3	6.0	8.0	15.5	10.3	6.7	7.7	15.1	17.0
	9.0	9.0	2.7	4.3	8.8	8.8	9.3	11.8	12.1	8.5	7.6	6.7
		18.0	5.8	5.9	5.3	11.2	12.6	11.0	6.3	7.6	16.4	19.8
	11.0	10.0	5.5	4.8	10.1	11.9	17.0	12.9	9.9	7.1	9.1	7.4
		22.0	6.8	10.9	5.5	11.1	15.7	11.5	9.0	8.6	17.0	23.7
	13.0	9.0	5.5	7.5	8.2	12.8	15.3	12.6	8.6	7.1	7.1	6.8
		18.0	8.1	8.0	9.9	11.1	18.0	12.9	8.4	7.8	16.8	15.8
	15.0	7.0	6.1	7.8	9.2	11.2	13.7	13.7	10.4	8.5	4.7	5.0
		14.0	8.6	8.4	9.7	13.1	17.6	14.2	10.9	10.2	13.6	13.3
	17.0	6.0	7.0	10.9	10.5	8.2	9.3	10.2	10.5	10.3	2.7	4.0
		12.0	8.7	10.1	11.9	17.0	19.2	16.1	8.9	8.1	15.9	11.1
	19.0	6.0	7.0	6.8	8.8	11.2	14.8	10.1	9.1	7.1	4.8	3.6
		11.0	8.7	9.8	8.9	13.4	19.2	13.1	9.0	7.1	12.2	10.3

Table 11

Wave Heights for Plan 2 with Test Waves from North

Test Wave		Wave Height, ft									
Period sec	Height ft	Gage 5	Gage 6	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12	Gage 13	Gage 16	Gage 17
5.0	6.0	1.6	3.7	3.5	6.7	6.1	5.2	6.0	5.6	4.9	6.2
	12.0	4.1	7.7	5.9	9.6	11.3	9.9	8.3	6.0	9.9	12.4
7.0	8.0	5.2	5.2	6.8	11.0	8.6	8.7	9.7	9.8	5.1	6.7
	16.0	3.2	5.8	8.1	12.1	10.1	11.7	6.8	7.1	9.5	14.1
9.0	8.0	2.9	4.1	6.2	12.1	7.8	8.5	12.2	7.3	3.7	6.8
	16.0	7.0	8.1	6.9	10.6	12.5	15.9	7.8	6.7	13.8	13.7
	22.0	8.5	8.4	9.5	12.3	10.9	11.5	8.8	7.2	12.1	23.8
11.0	8.0	6.3	6.9	10.0	16.5	8.8	11.4	8.3	9.1	4.5	7.0
	16.0	7.8	6.8	8.7	12.2	11.5	12.8	7.1	8.5	15.0	18.7
13.0	9.0	8.2	8.0	9.6	23.0	11.5	13.9	9.3	7.5	4.5	7.3
	18.0	9.1	9.7	8.9	15.1	11.9	15.5	9.5	8.6	14.6	17.7
15.0	9.0	5.7	5.4	10.0	18.3	9.1	11.2	9.7	7.3	4.5	6.1
	18.0	7.8	9.5	8.4	17.1	15.7	14.5	10.6	8.2	12.1	14.1
17.0	6.0	1.8	3.2	7.4	15.9	8.0	8.3	9.0	6.4	3.3	4.4
	12.0	7.7	10.8	8.7	12.6	11.8	14.3	8.1	9.1	6.9	9.0
19.0	4.0	1.4	1.9	3.1	8.8	4.1	8.2	13.0	10.7	1.5	3.0
	8.0	6.3	6.2	8.1	19.6	9.0	15.0	9.7	9.4	4.1	6.9

Table 12

Wave Heights for Plan 7A with Test Waves from Northwest

Test Wave		Wave Height, ft																	
Period sec	Height ft	Gage 5	Gage 40	Gage 41	Gage 7	Gage 42	Gage 14	Gage 43	Gage 44	Gage 45	Gage 46	Gage 47	Gage 48	Gage 49	Gage 50	Gage 51	Gage 16	Gage 52	Gage 17
5.0	6.0	3.9	3.6	4.6	4.3	1.5	1.5	2.6	2.1	5.3	6.6	5.7	5.4	5.6	6.1	6.9	5.9	5.5	6.9
	12.0	6.2	5.7	7.4	5.2	6.1	5.4	4.4	3.3	10.5	9.3	10.4	10.8	6.4	6.2	14.7	13.9	11.5	12.3
7.0	8.0	7.2	8.1	6.4	8.3	5.8	3.7	3.8	4.3	7.1	10.8	13.5	11.9	8.2	6.4	7.5	5.6	6.1	7.8
	16.0	8.6	7.5	9.8	8.5	7.7	6.6	4.2	4.1	16.1	14.9	12.6	11.9	9.7	5.8	18.3	16.9	17.7	15.0
9.0	8.0	6.4	5.4	3.6	4.8	5.0	3.8	3.3	3.6	4.4	8.9	9.9	12.9	10.3	8.3	4.7	5.6	5.7	6.4
	16.0	10.6	9.6	8.4	9.0	8.4	7.7	6.2	7.0	12.8	14.7	16.0	14.4	8.7	8.6	16.6	15.5	16.4	18.6
10.0	12.0	8.5	5.0	7.4	7.7	5.6	6.0	7.9	6.0	5.9	13.1	14.5	12.0	10.5	8.0	12.5	9.2	9.7	11.8
11.0	6.0	4.2	4.0	6.8	5.7	3.4	3.5	3.3	3.3	3.0	8.9	10.3	9.5	10.2	7.8	6.5	4.3	4.8	5.7
	12.0	10.0	9.3	8.2	9.7	8.5	8.9	11.3	7.3	7.7	17.5	15.7	11.6	8.5	7.4	11.5	12.4	11.5	12.3
13.0	8.0	6.2	8.4	8.4	6.2	4.0	2.6	5.0	6.7	4.7	14.7	13.0	10.9	8.5	6.9	5.4	7.2	8.4	8.2
	16.0	8.9	8.4	10.6	9.4	9.5	7.1	9.2	7.2	18.6	12.5	17.3	12.8	9.1	7.5	14.6	16.0	19.1	24.3
15.0	6.0	4.1	6.3	5.9	7.1	6.1	3.1	3.1	3.9	3.3	10.1	15.8	12.9	11.1	6.7	4.9	4.9	4.9	4.1
	10.0	8.6	9.3	8.5	8.0	7.4	5.8	8.2	7.4	6.5	16.8	16.3	17.1	9.5	7.5	6.4	8.4	8.2	6.5
17.0	4.0	1.3	2.1	3.1	3.1	2.2	1.1	2.1	2.8	3.8	5.6	8.2	6.5	7.9	7.1	2.4	3.4	3.6	4.6
	8.0	6.5	6.4	10.6	7.0	4.9	4.1	6.4	6.5	7.2	15.2	16.9	16.7	8.9	6.1	6.1	7.2	7.3	9.0
19.0	4.0	2.5	3.3	3.8	2.7	1.8	1.2	1.7	2.0	2.5	6.5	6.7	6.2	6.1	8.4	3.5	3.5	4.2	5.6

Table 13

Wave Heights for Plan 7A with Test Waves from North

Test Wave		Wave Height, ft																	
Period sec	Height ft	Gage 5	Gage 40	Gage 41	Gage 7	Gage 42	Gage 14	Gage 43	Gage 44	Gage 45	Gage 46	Gage 47	Gage 48	Gage 49	Gage 50	Gage 51	Gage 16	Gage 52	Gage 17
5.0	6.0	1.9	2.3	3.5	1.8	0.4	1.2	1.6	1.0	8.2	6.2	6.1	5.1	8.7	7.4	6.0	5.7	6.9	6.6
	12.0	3.7	3.7	4.9	2.7	1.6	1.7	1.8	1.4	12.1	12.1	15.0	10.5	8.3	7.9	11.0	10.8	12.5	13.2
7.0	8.0	5.2	3.7	3.3	6.2	4.3	3.1	2.2	2.7	5.7	11.1	13.3	5.7	9.2	7.0	4.7	5.1	4.8	7.6
	16.0	4.7	4.6	6.0	4.4	4.4	4.7	3.7	2.5	10.1	12.4	18.8	9.4	7.4	6.9	11.9	9.4	13.7	14.0
9.0	8.0	3.6	3.2	1.6	3.5	3.0	3.8	3.2	3.6	4.0	11.7	11.8	9.6	11.6	8.1	4.2	3.1	5.0	6.5
	16.0	5.2	5.0	4.8	6.2	6.6	6.6	5.9	4.1	12.3	10.2	21.8	8.0	7.9	8.0	10.6	15.0	18.1	17.3
	22.0	8.4	6.8	7.7	8.1	7.9	7.8	6.3	4.6	10.4	9.4	19.1	8.9	11.1	6.9	16.5	14.7	13.2	25.9
10.0	12.0	6.6	6.1	6.6	6.7	5.2	6.8	5.4	4.0	13.9	13.3	13.8	13.9	8.6	6.3	8.1	7.8	9.9	10.1
11.0	8.0	3.5	3.2	3.2	7.1	5.1	5.7	4.5	5.3	6.8	16.1	15.5	13.1	8.5	8.1	5.1	5.7	6.1	8.8
	16.0	6.2	6.1	7.1	6.7	6.9	7.3	7.4	5.0	15.9	13.4	17.4	10.8	8.0	7.9	13.6	15.3	14.6	17.6
13.0	9.0	6.2	5.7	8.2	7.8	5.4	5.3	5.0	6.8	8.9	14.9	15.8	13.1	8.0	8.9	5.6	5.3	6.4	6.3
	18.0	9.4	9.9	8.4	8.9	8.8	8.0	7.1	4.5	15.4	10.9	18.3	10.4	9.3	8.4	16.9	22.0	24.7	19.6
15.0	9.0	3.8	5.3	5.2	8.3	5.6	6.2	6.0	6.9	8.3	17.6	14.6	11.8	8.4	8.0	3.1	3.2	3.2	6.1
	18.0	7.9	7.7	7.9	7.7	7.0	6.6	7.4	5.3	20.8	13.1	18.3	15.8	8.4	7.6	15.1	15.6	14.6	14.8
17.0	6.0	1.3	2.0	3.4	3.1	3.9	4.2	5.5	4.8	5.2	14.1	12.6	8.3	9.5	6.7	3.5	3.3	2.2	5.9
	12.0	8.3	8.9	8.4	7.4	7.2	7.1	7.1	7.0	16.7	13.5	20.9	10.6	8.4	6.5	6.8	8.3	8.0	11.1
19.0	4.0	1.2	1.9	2.1	2.2	2.2	2.6	3.3	3.6	4.8	7.9	8.9	6.2	12.2	8.3	1.7	2.5	3.9	3.4
	8.0	3.9	5.8	6.0	6.9	6.8	6.3	8.4	8.5	11.6	15.6	21.5	16.1	9.3	7.7	4.2	5.2	6.7	6.7

Table 14

Wave Heights for Plan 7A with Test Waves from Northeast

Test Wave		Wave Height, ft																	
Period sec	Height ft	Gage 5	Gage 40	Gage 41	Gage 7	Gage 42	Gage 14	Gage 43	Gage 44	Gage 45	Gage 46	Gage 47	Gage 48	Gage 49	Gage 50	Gage 51	Gage 16	Gage 52	Gage 17
5.0	6.0	0.9	0.6	1.0	0.5	0.2	0.6	0.8	0.4	4.6	5.5	5.4	7.8	5.9	9.0	4.2	6.7	6.0	5.2
	12.0	2.1	1.9	3.0	2.7	1.4	1.2	1.5	0.9	7.9	10.5	9.8	8.9	7.2	7.7	7.7	9.5	11.0	10.2
7.0	8.0	2.6	2.6	3.4	7.9	4.3	1.6	1.6	2.0	8.3	7.3	11.0	14.1	11.3	8.2	6.9	7.3	5.5	4.5
	16.0	4.1	5.4	7.9	7.3	4.0	2.7	2.2	1.7	10.7	13.2	10.9	8.1	8.2	8.0	13.5	14.8	18.4	15.1
9.0	9.0	4.0	4.5	4.6	4.9	5.5	5.7	3.6	1.9	13.9	7.4	11.1	14.8	12.7	8.1	5.5	5.7	4.9	3.6
	18.0	6.0	4.6	6.5	7.5	3.9	4.2	2.7	2.4	10.0	13.5	11.5	9.4	8.3	9.3	14.3	18.3	20.7	19.7
10.0	12.0	6.1	4.6	5.7	7.3	5.7	5.0	3.2	2.3	16.3	15.6	11.8	9.6	8.8	7.9	10.1	9.5	11.0	8.8
11.0	10.0	5.6	5.4	5.9	7.3	6.4	5.0	3.3	3.0	13.8	13.3	11.0	11.2	6.9	7.4	11.0	8.8	9.6	8.0
	22.0	6.7	6.8	8.0	5.2	5.1	3.4	4.3	4.8	9.6	14.5	10.1	8.9	7.2	8.0	16.3	16.9	17.6	22.8
13.0	9.0	8.9	5.8	6.9	8.1	6.6	5.2	3.9	3.0	17.2	13.1	10.3	10.1	7.8	8.2	8.1	11.8	12.1	7.2
	18.0	7.0	7.9	8.7	10.0	8.0	4.5	3.3	2.5	12.4	16.8	11.5	9.9	8.6	7.6	15.3	18.1	17.0	20.1
15.0	7.0	7.8	7.3	7.1	9.6	6.6	4.7	3.5	3.8	13.8	11.3	8.4	9.5	7.7	6.7	4.7	4.7	5.4	3.5
	14.0	6.1	7.7	8.0	8.1	6.9	4.5	3.7	2.9	21.0	16.9	10.9	9.1	6.8	7.4	11.3	12.0	14.5	10.2
17.0	6.0	6.2	7.2	8.9	7.5	5.5	3.9	3.8	3.6	11.0	9.7	8.5	14.3	11.8	6.4	2.7	3.3	4.8	3.8
	12.0	8.7	8.1	7.8	8.5	5.9	5.2	4.3	3.2	20.7	17.3	11.0	9.1	7.7	7.9	9.5	11.5	11.3	11.7
19.0	6.0	5.0	6.8	8.3	7.8	4.1	4.0	3.8	3.6	13.1	12.9	10.1	9.7	8.5	6.6	3.7	4.7	4.0	3.7
	11.0	8.5	9.8	8.1	9.1	8.6	4.5	3.4	2.6	14.4	13.6	11.5	8.9	12.1	7.4	11.4	17.1	17.9	11.4

Table 15

Wave Heights for Plan 7A (Gages 53-60) with

Test Waves from Northwest and North

Test Wave			Wave Height, ft							
Direction	Period sec	Height ft	Gage 53	Gage 54	Gage 55	Gage 56	Gage 57	Gage 58	Gage 59	Gage 60
Northwest	10.0	12.0	10.7	5.4	5.4	6.2	6.5	5.2	3.8	5.8
	11.0	12.0	8.6	6.2	4.7	6.8	6.9	5.1	4.7	5.5
	13.0	16.0	16.7	5.4	6.3	7.2	8.0	6.4	5.7	7.0
	15.0	10.0	6.3	6.0	4.8	5.8	7.1	6.0	5.0	6.6
	17.0	8.0	4.8	7.2	5.7	7.1	6.8	5.6	4.8	7.0
North	7.0	16.0	7.4	3.9	3.7	3.8	4.4	4.6	2.8	7.0
	9.0	16.0	9.1	4.8	4.2	6.2	6.4	4.6	4.8	6.8
	9.0	22.0	7.0	5.9	3.9	7.1	6.0	3.6	4.0	7.3
	10.0	12.0	8.5	5.9	3.8	7.1	6.5	7.2	5.0	6.7
	13.0	18.0	13.2	5.6	4.9	5.3	7.6	7.8	5.4	7.6
	15.0	18.0	10.7	6.9	8.6	5.9	5.7	7.4	6.4	7.2
	17.0	12.0	5.2	5.1	7.0	6.7	7.2	6.9	5.5	6.6

Table 16

Rock Volumes for Improvement

Plans at El Morro Castle

Plan Number	Approximate Volume of Rock Required, cu yd
1	105,360
2	182,700
2A	190,790
2B	212,035
2C	256,480
2D	384,255
2E	401,810
2F	279,560
2G	411,410
3	76,465
3A	89,745
3B	119,590
3C	149,590
3D	104,665
4	185,935
4A	202,500
4B	215,780
5	159,375
5A	202,500
5B	232,500
5C	175,975
6	146,095
6A	168,095
6B	199,220
7	74,220
7A	156,250
7B	154,700
7C	153,125
7D	140,625

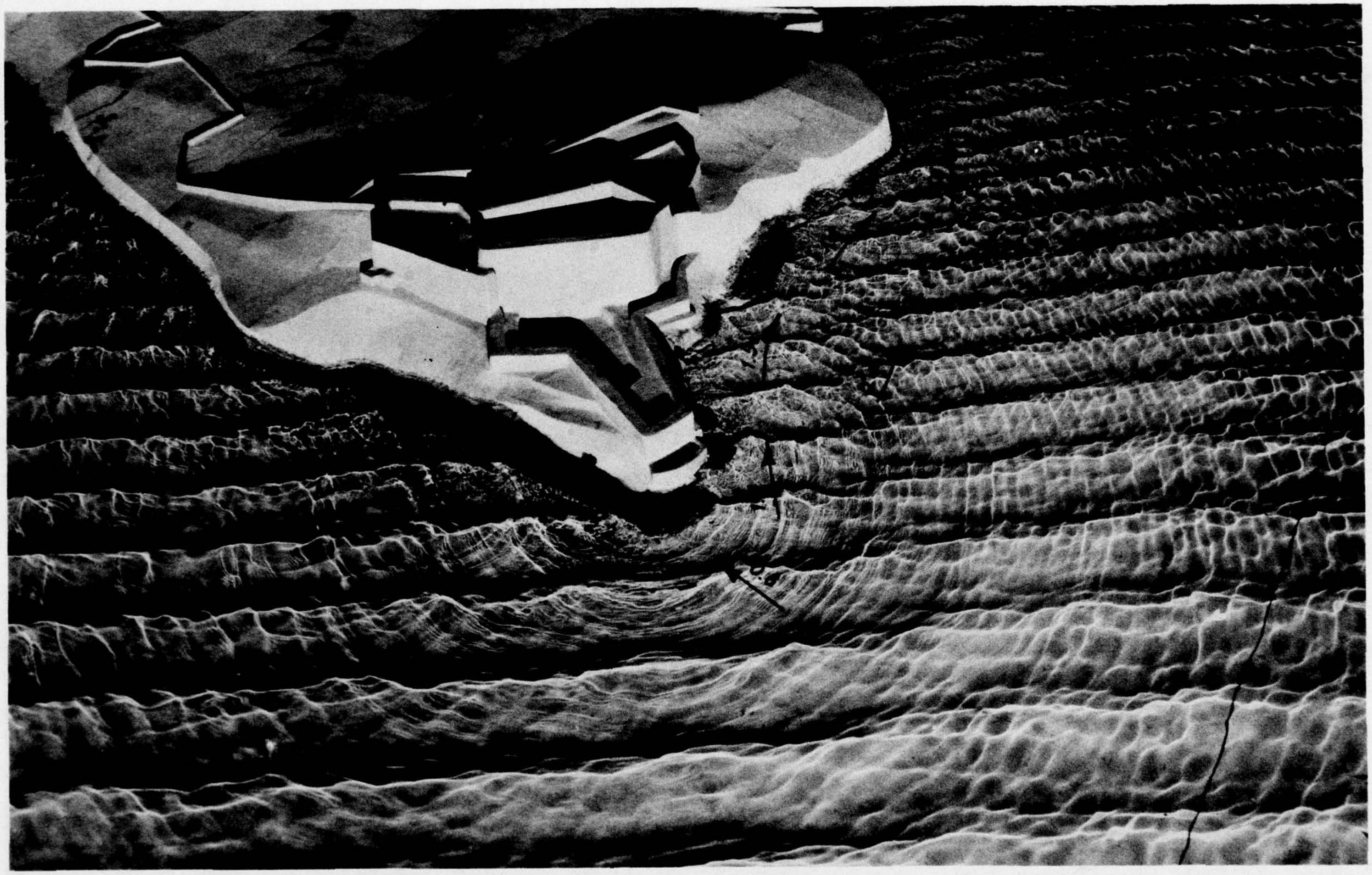


Photo 1. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 5-sec, 6-ft waves from northwest

Photo 2. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 16-ft waves from northwest

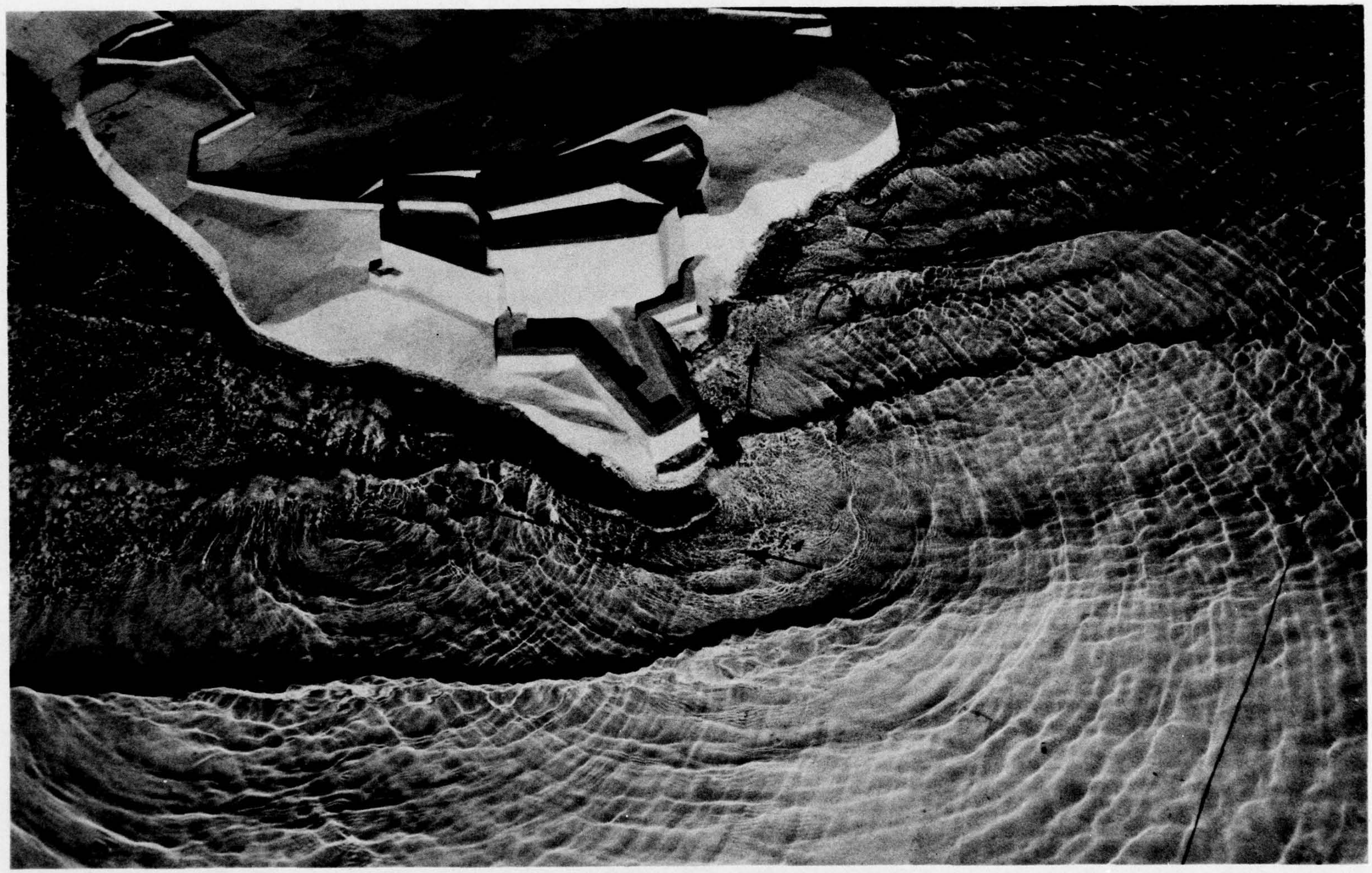


Photo 3. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 8-ft waves from northwest

Photo 4. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 16-ft waves from northwest

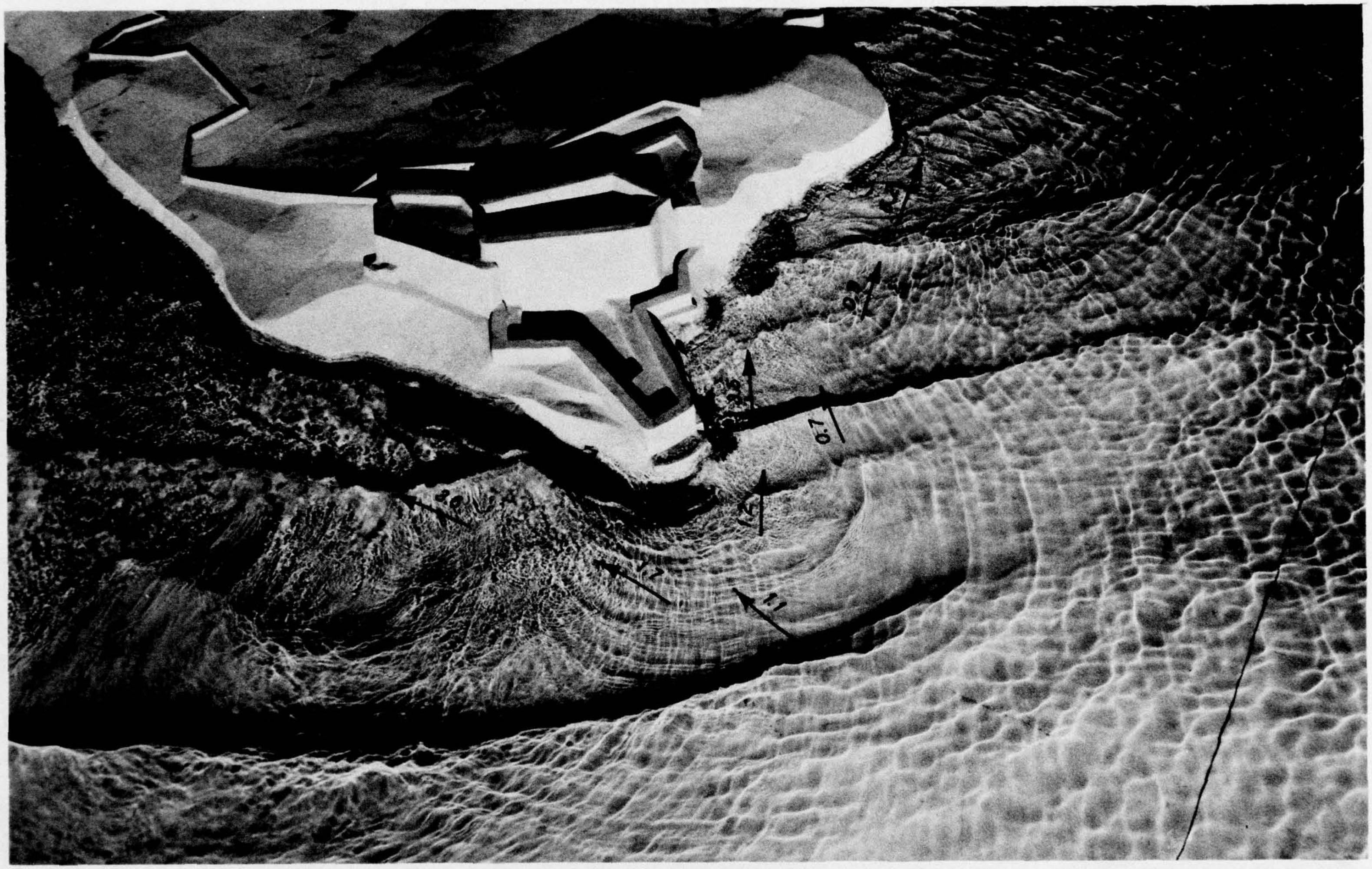


Photo 5. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 10-ft waves from northwest

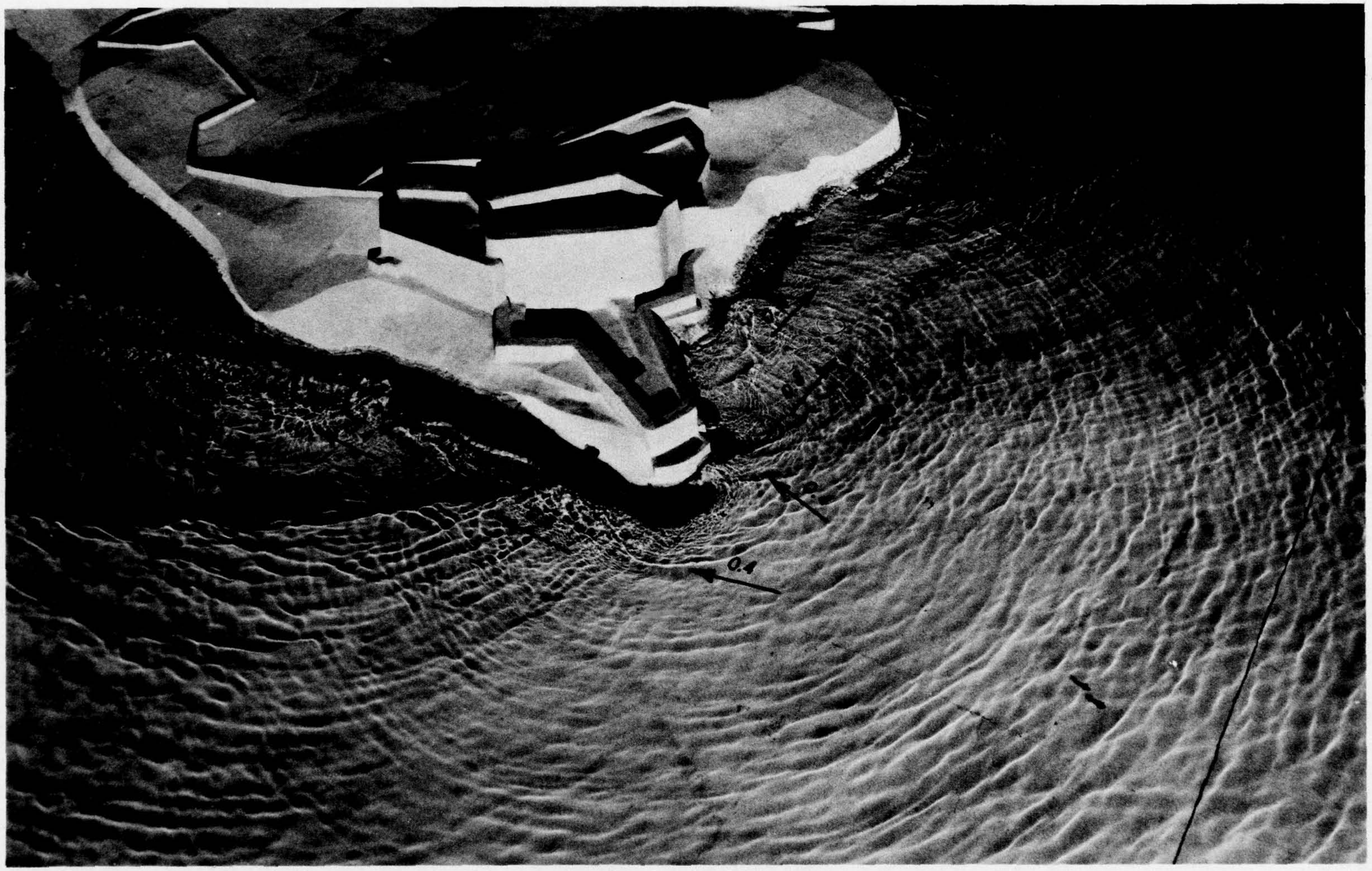


Photo 6. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 19-sec, 4-ft waves from northwest

Photo 7. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 5-sec, 6-ft waves from north

Photo 8. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 22-ft waves from north

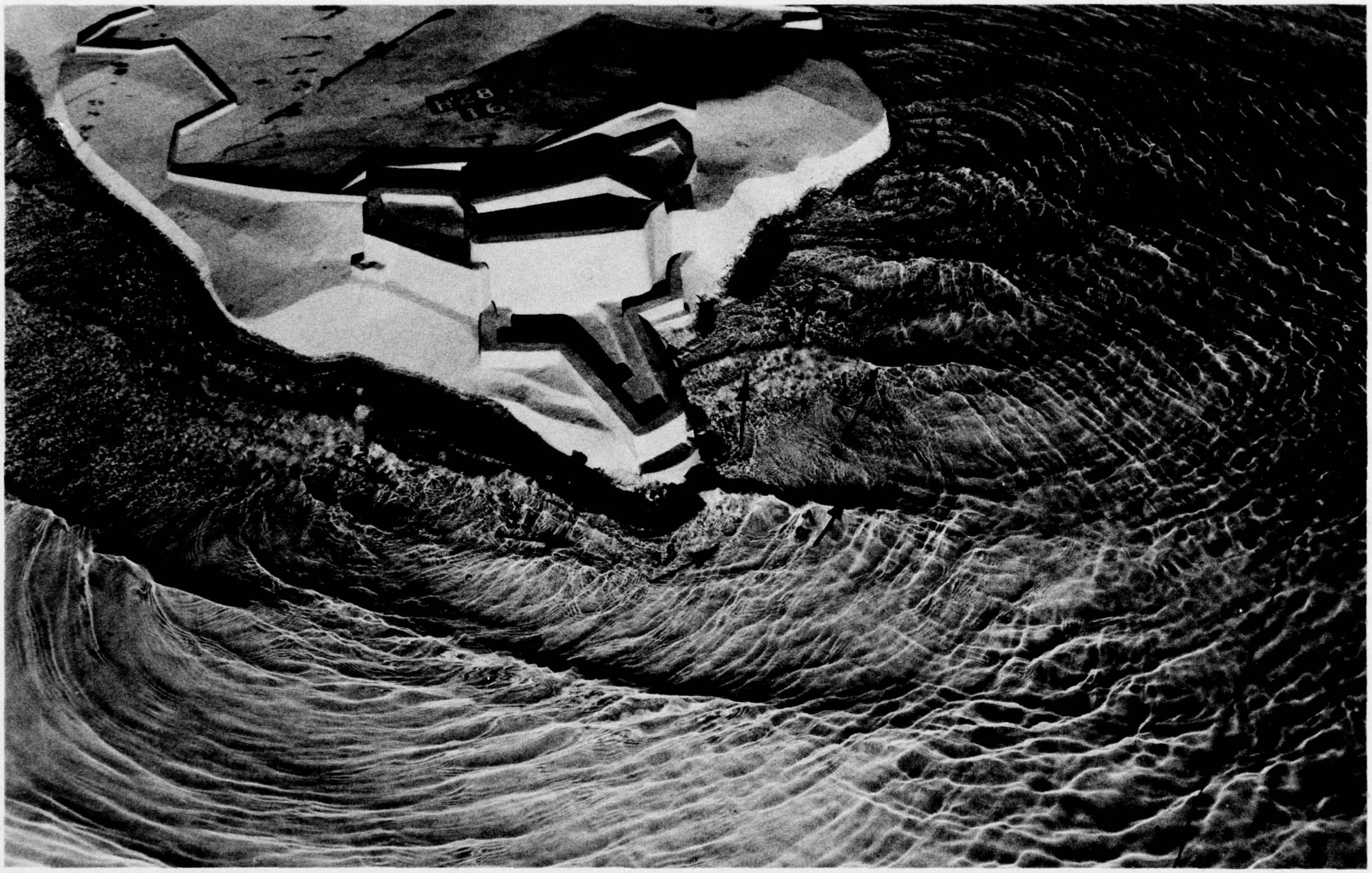


Photo 9. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditons; 11-sec, 8-ft waves from north

Photo 10. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 16-ft waves from north

Photo 11. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 18-ft waves from north

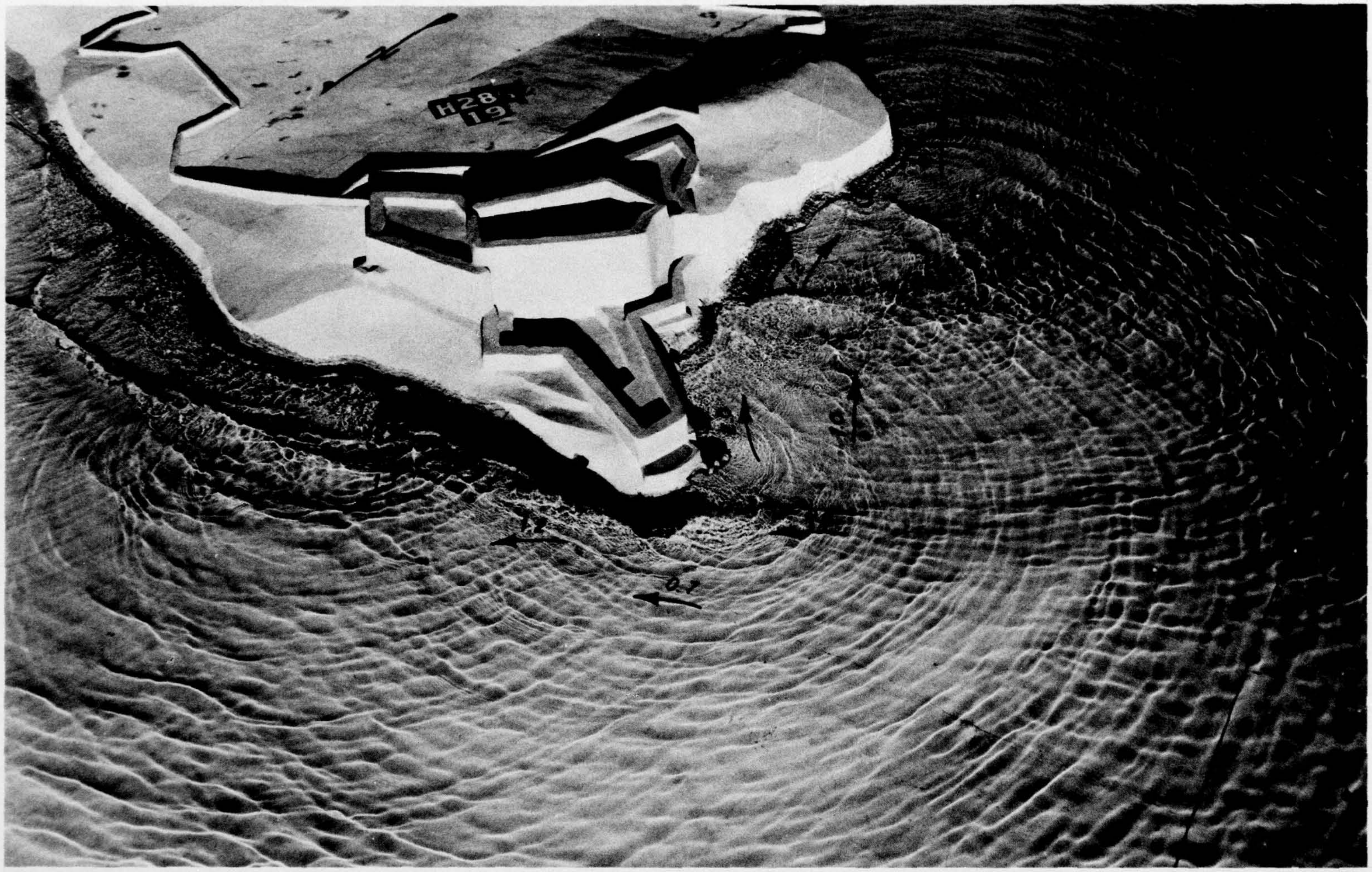


Photo 12. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 19-sec, 4-ft waves from north

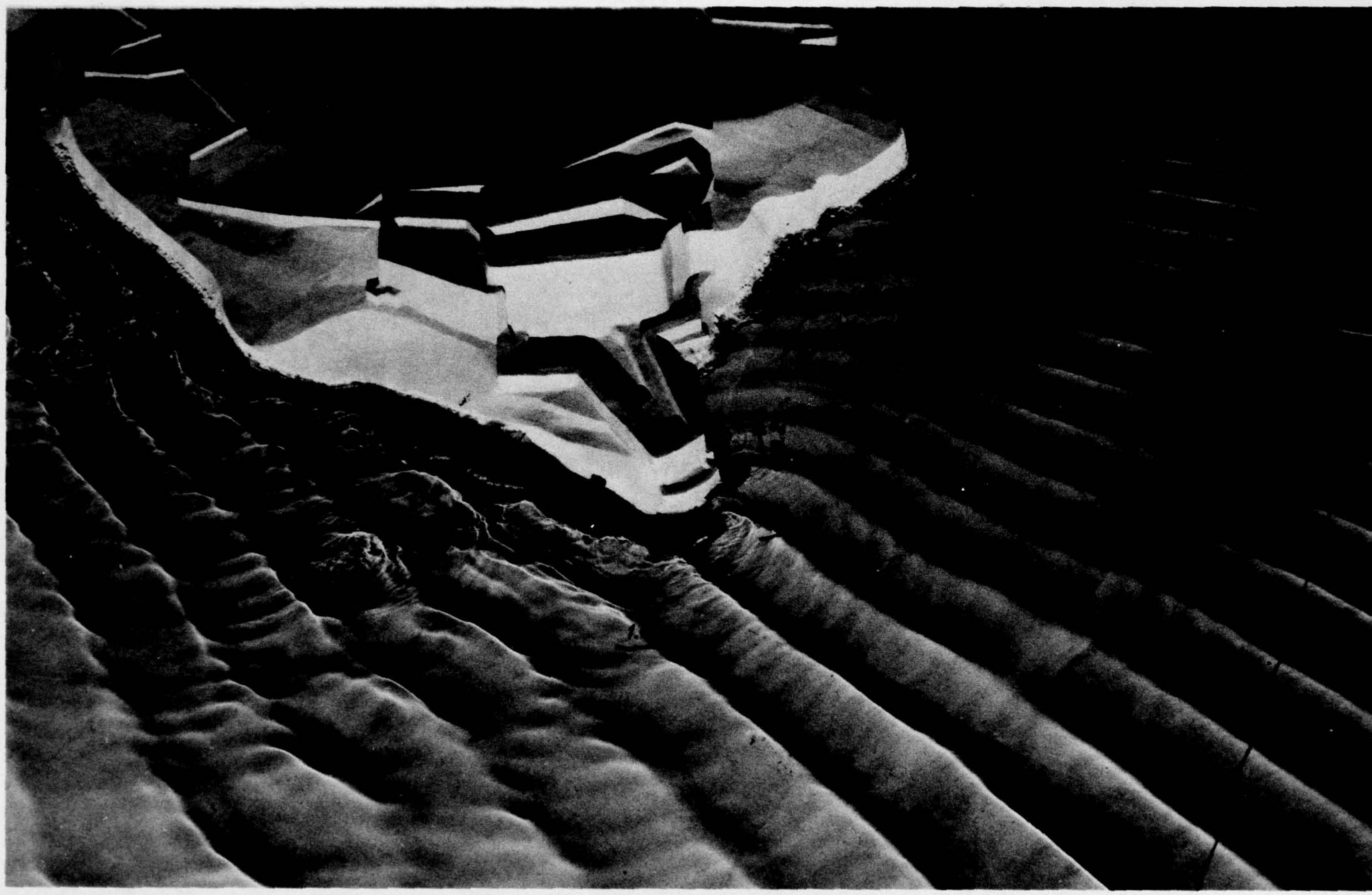


Photo 13. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 5-sec, 6-ft waves from northeast

Photo 14. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 18-ft waves from northeast

Photo 15. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 10-ft waves from northeast

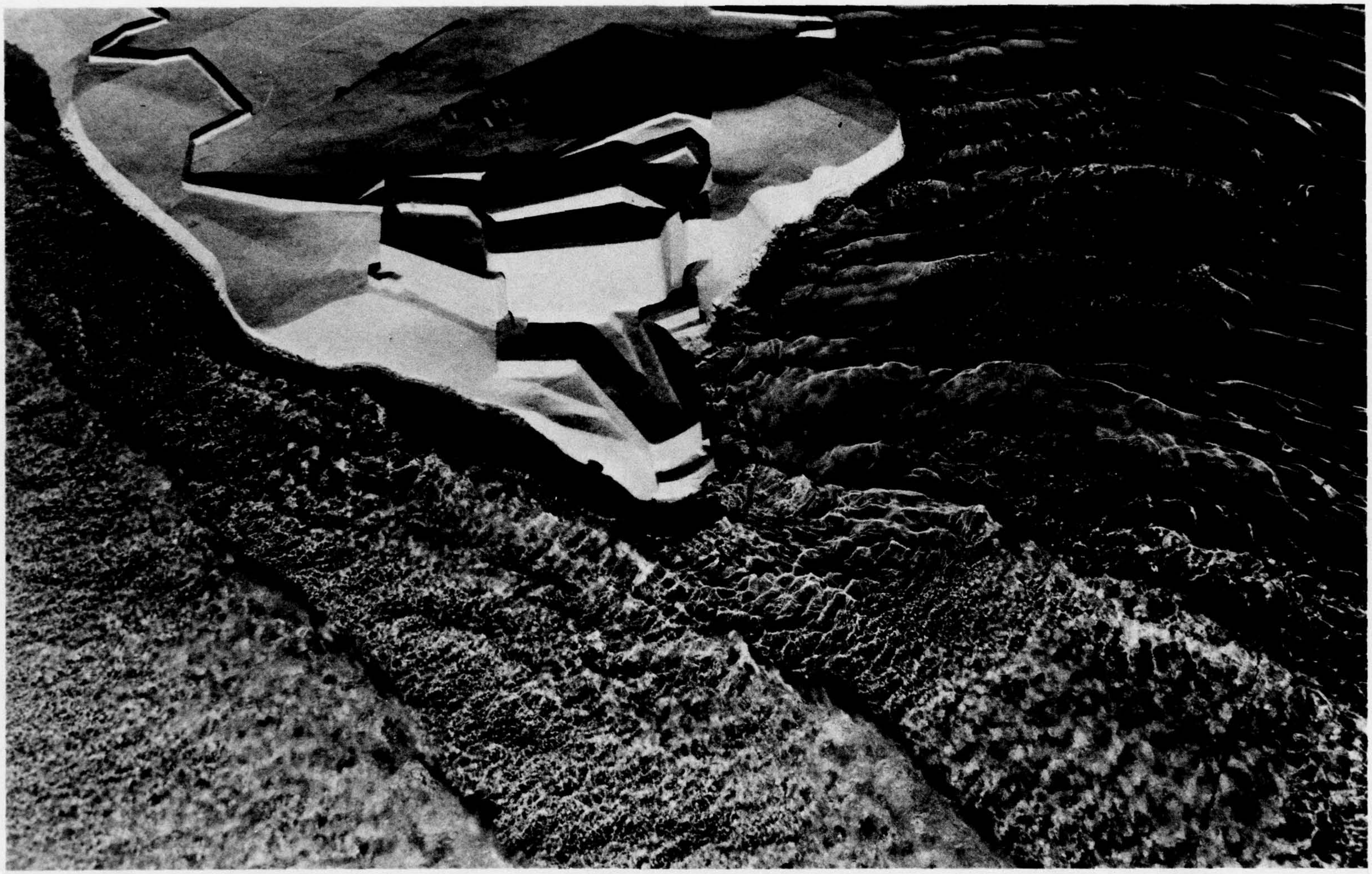


Photo 16. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 22-ft waves from northeast

Photo 17. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 14-ft waves from northeast

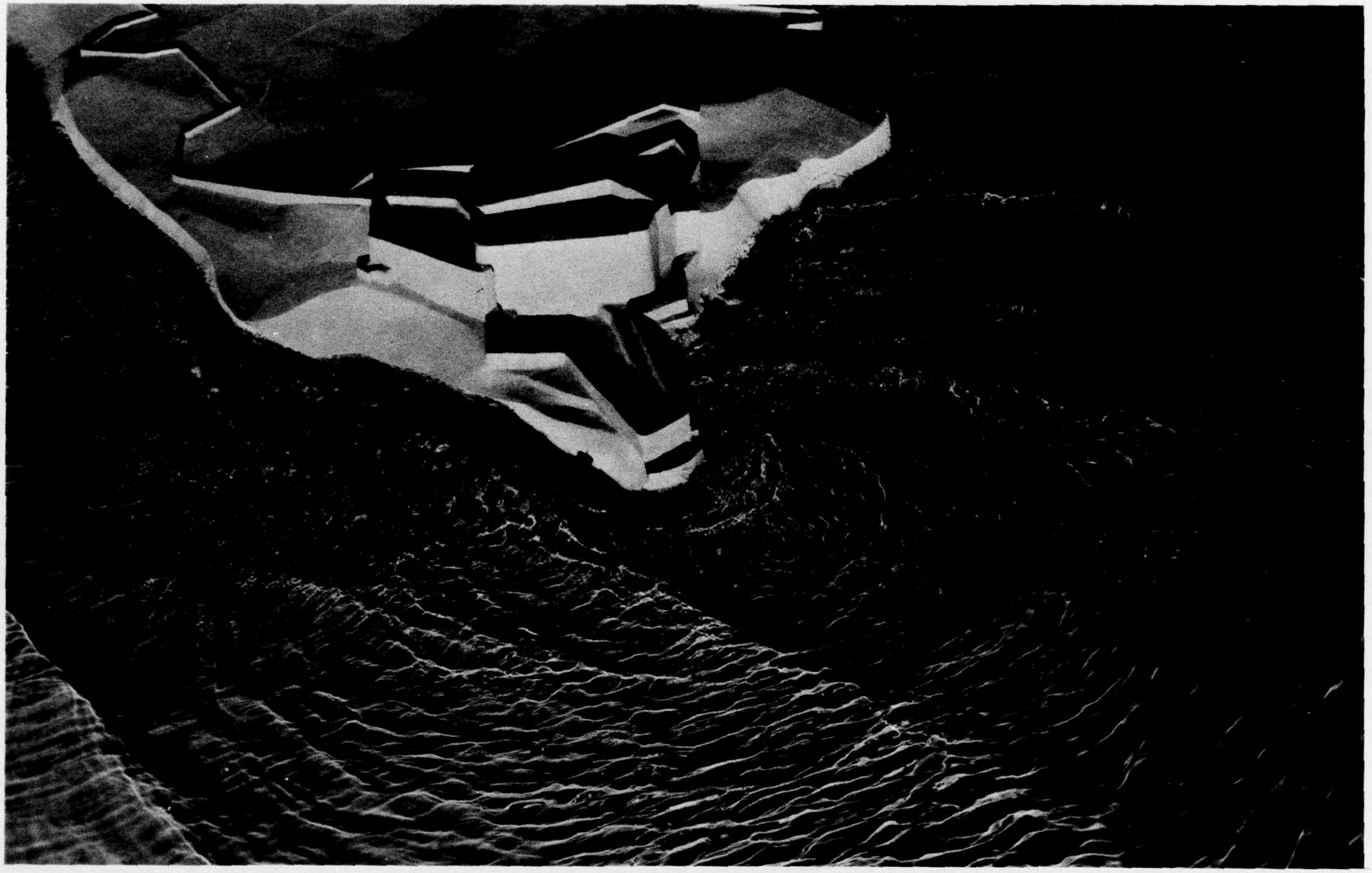


Photo 18. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 19-sec, 6-ft waves from northeast

Photo 19. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 5-sec, 6-ft waves from northwest

Photo 20. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 9-sec, 16-ft waves from northwest

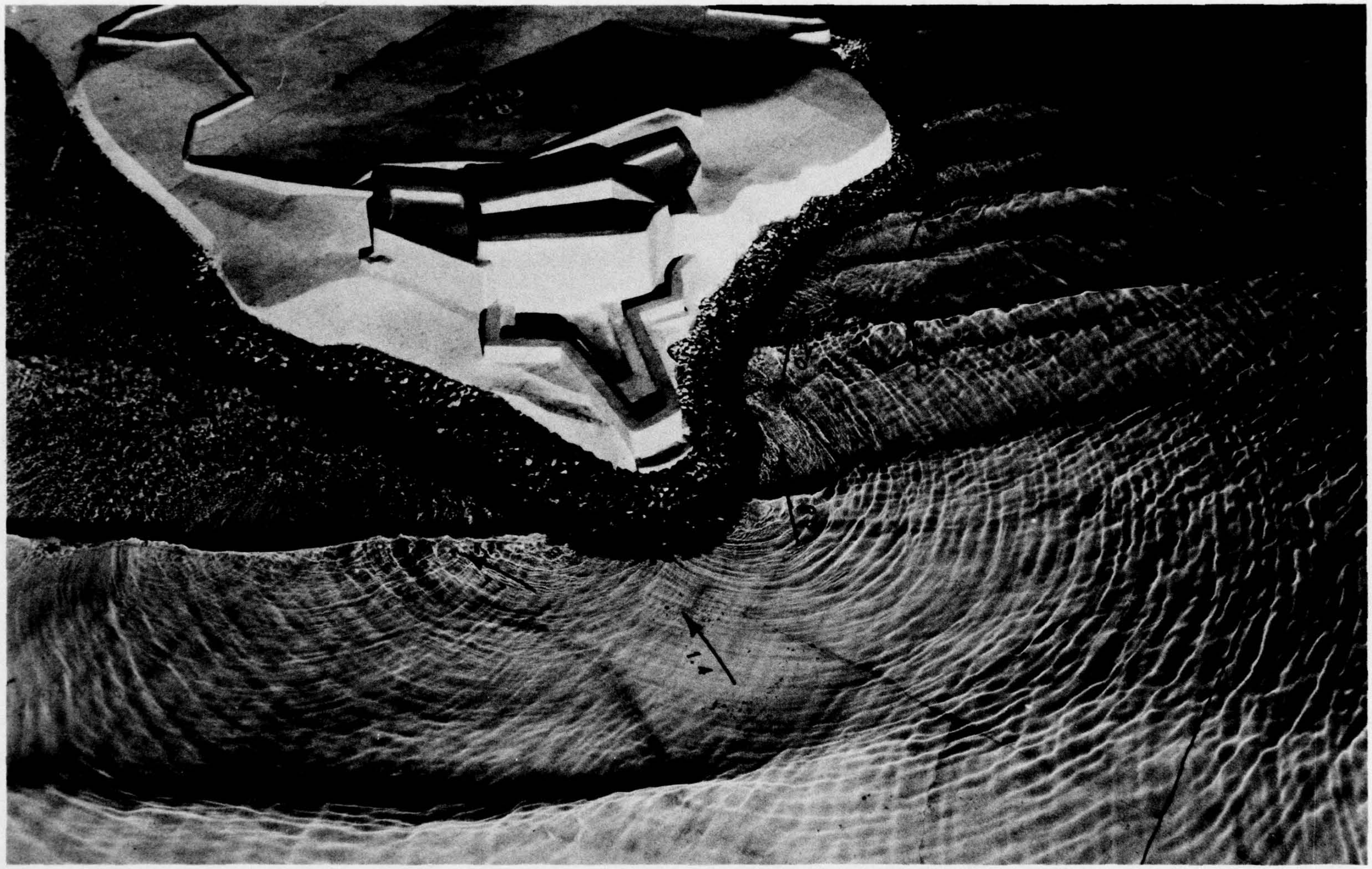


Photo 21. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 13-sec, 8-ft waves from northwest

Photo 22. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 13-sec, 16-ft waves from northwest

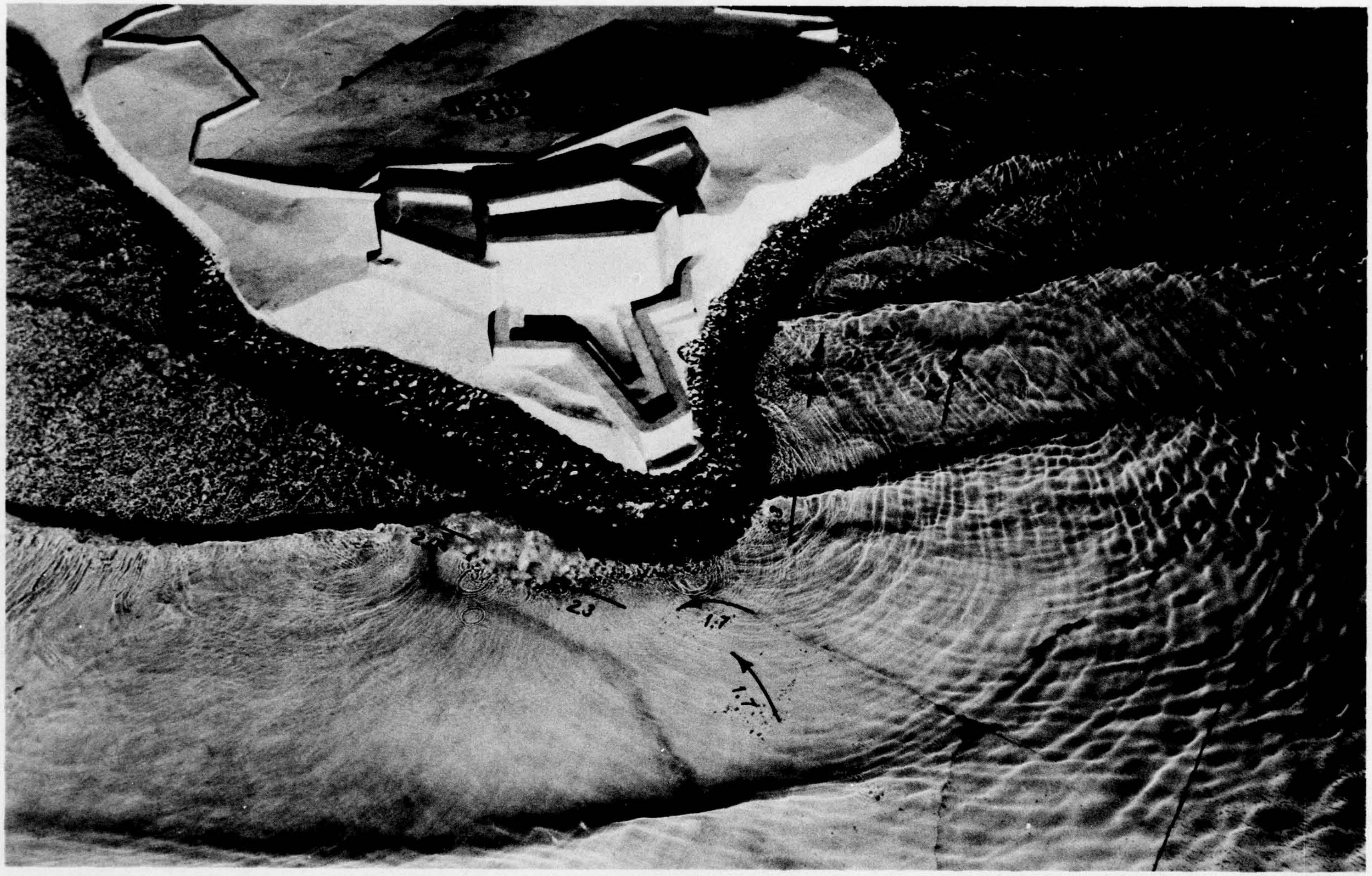


Photo 23. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 15-sec, 10-ft waves from northwest

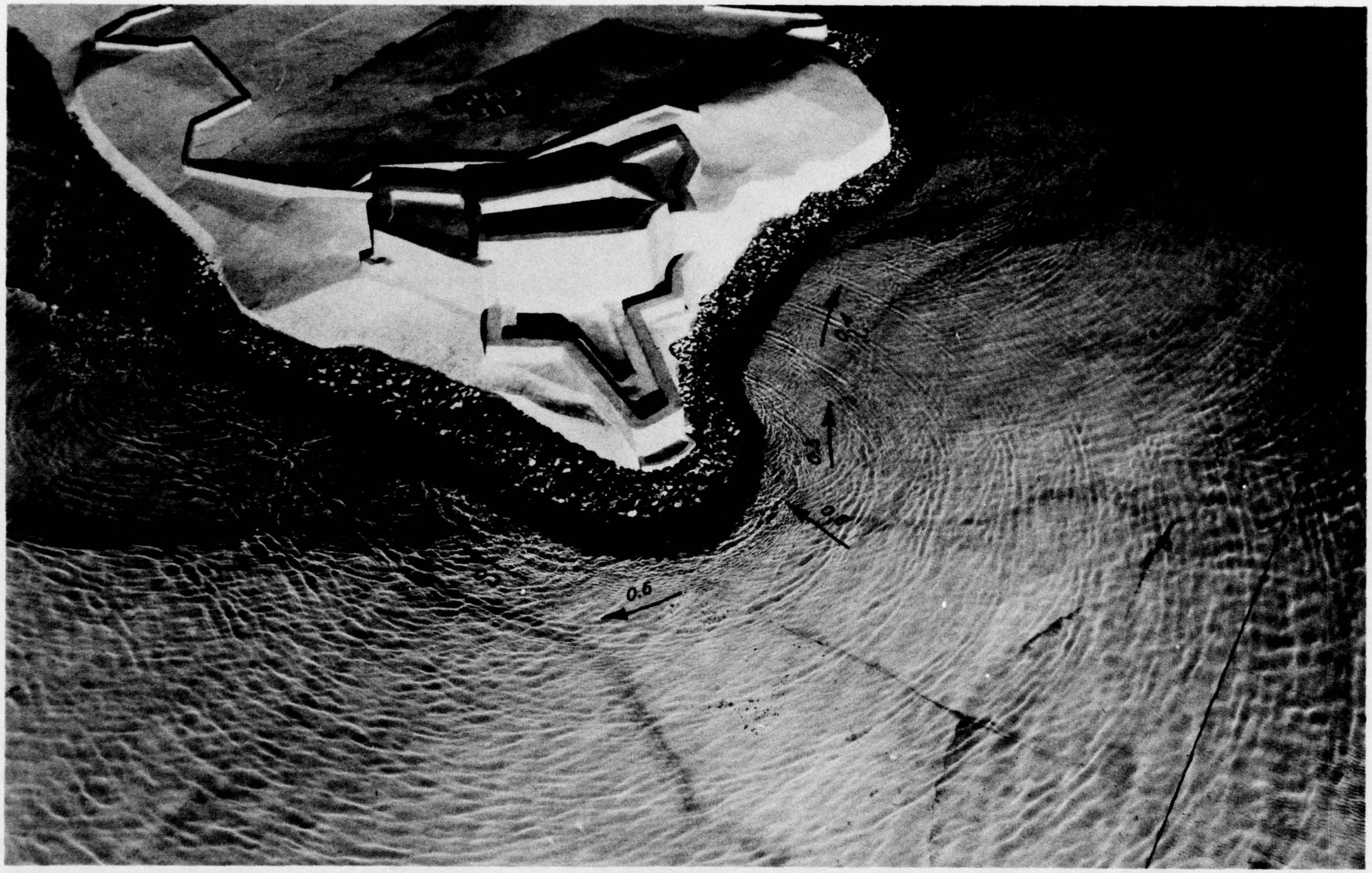


Photo 24. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 19-sec, 4-ft waves from northwest

Photo 25. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 5-sec, 6-ft waves from north

Photo 26. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 9-sec, 22-ft waves from north

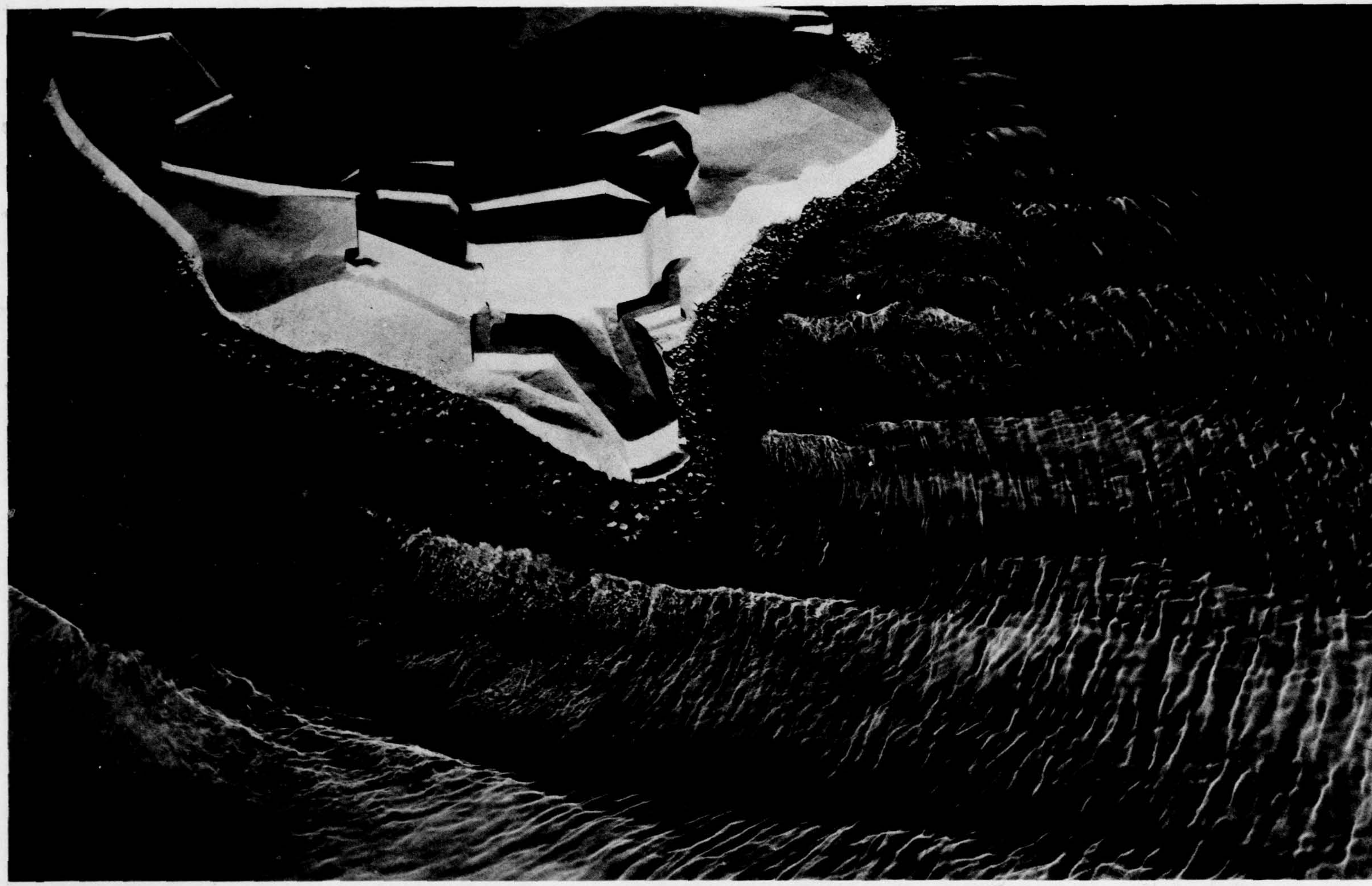


Photo 27. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 11-sec, 8-ft waves from north

Photo 28. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 11-sec, 16-ft waves from north

Photo 29. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 15-sec, 18-ft waves from north

Photo 30. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 19-sec, 4-ft waves from north

Photo 31. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 5-sec, 6-ft waves from northeast

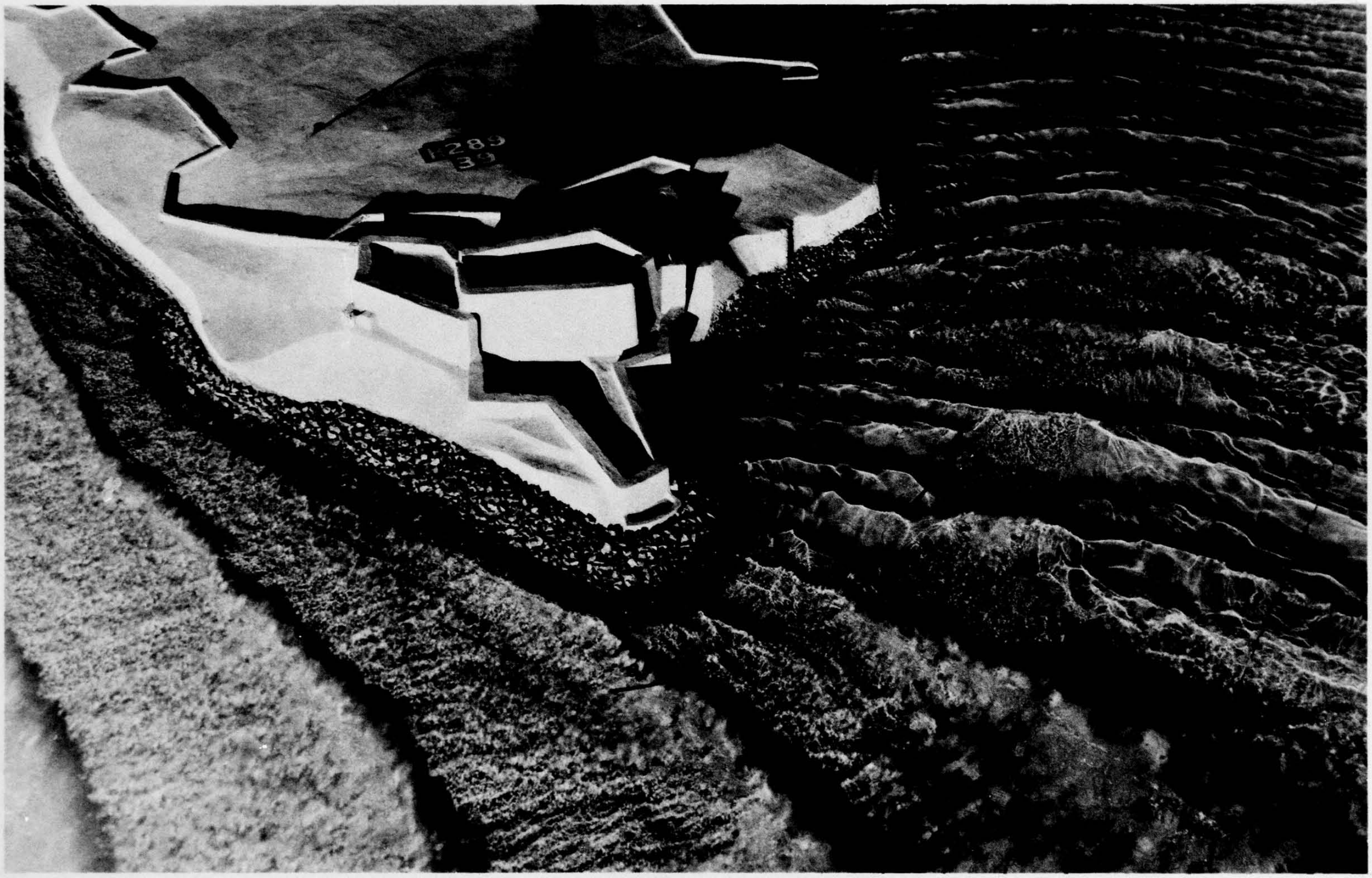


Photo 32. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 9-sec, 18-ft waves from northeast

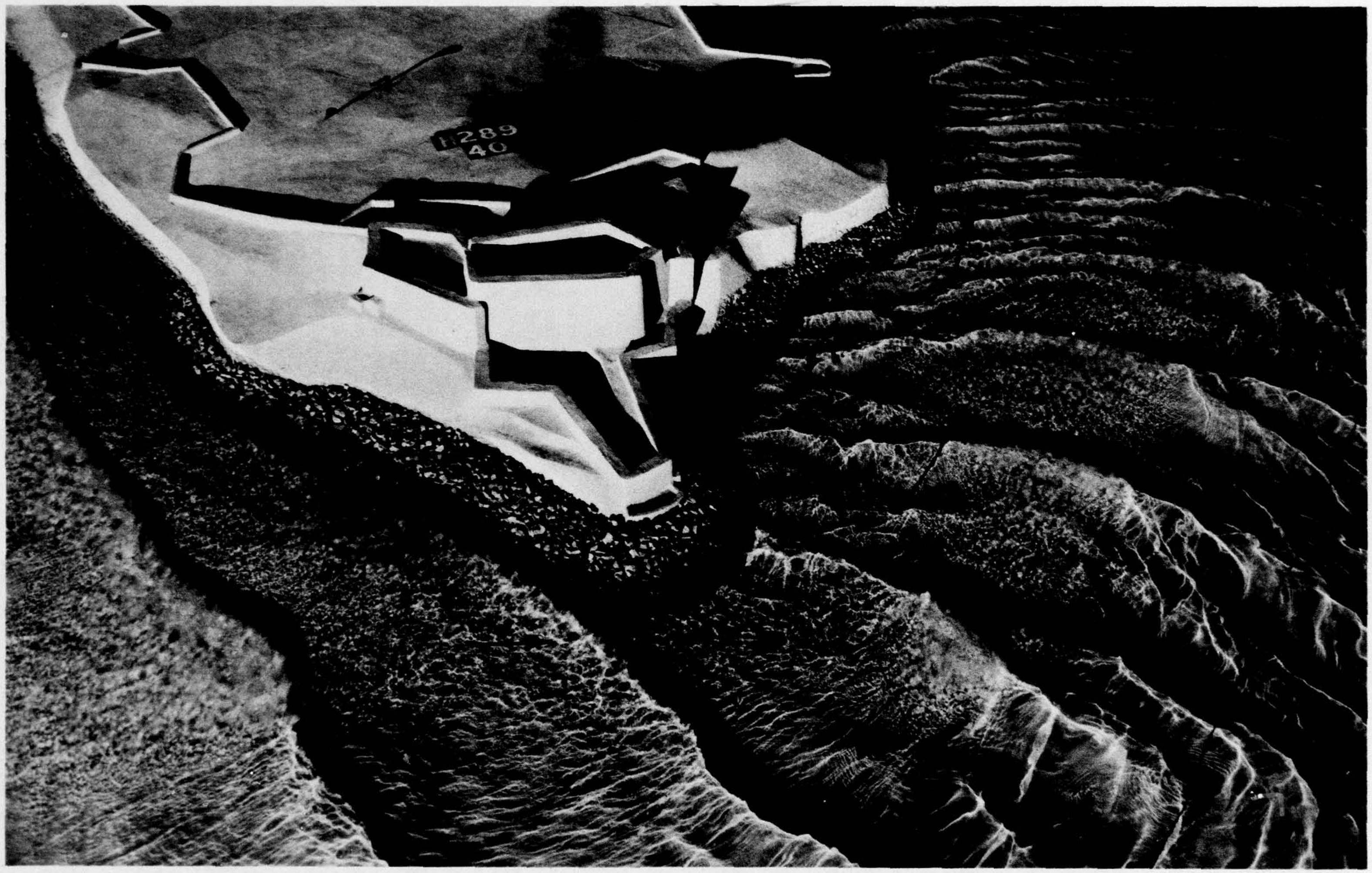


Photo 33. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 11-sec, 10-ft waves from northeast

Photo 34. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 11-sec, 22-ft waves from northeast

Photo 35. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 15-sec, 14-ft waves from northeast

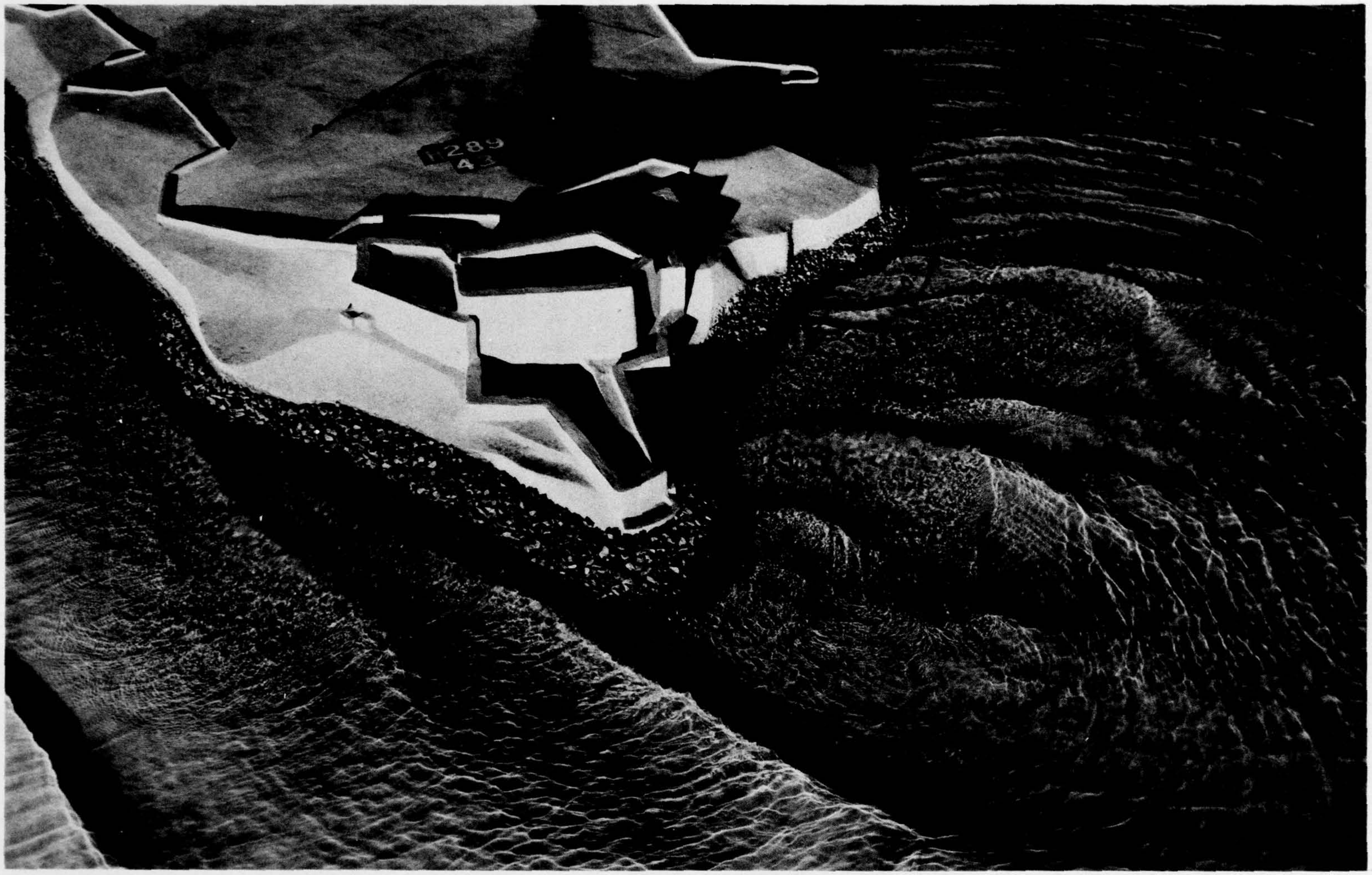


Photo 36. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 1; 19-sec, 6-ft waves from northeast

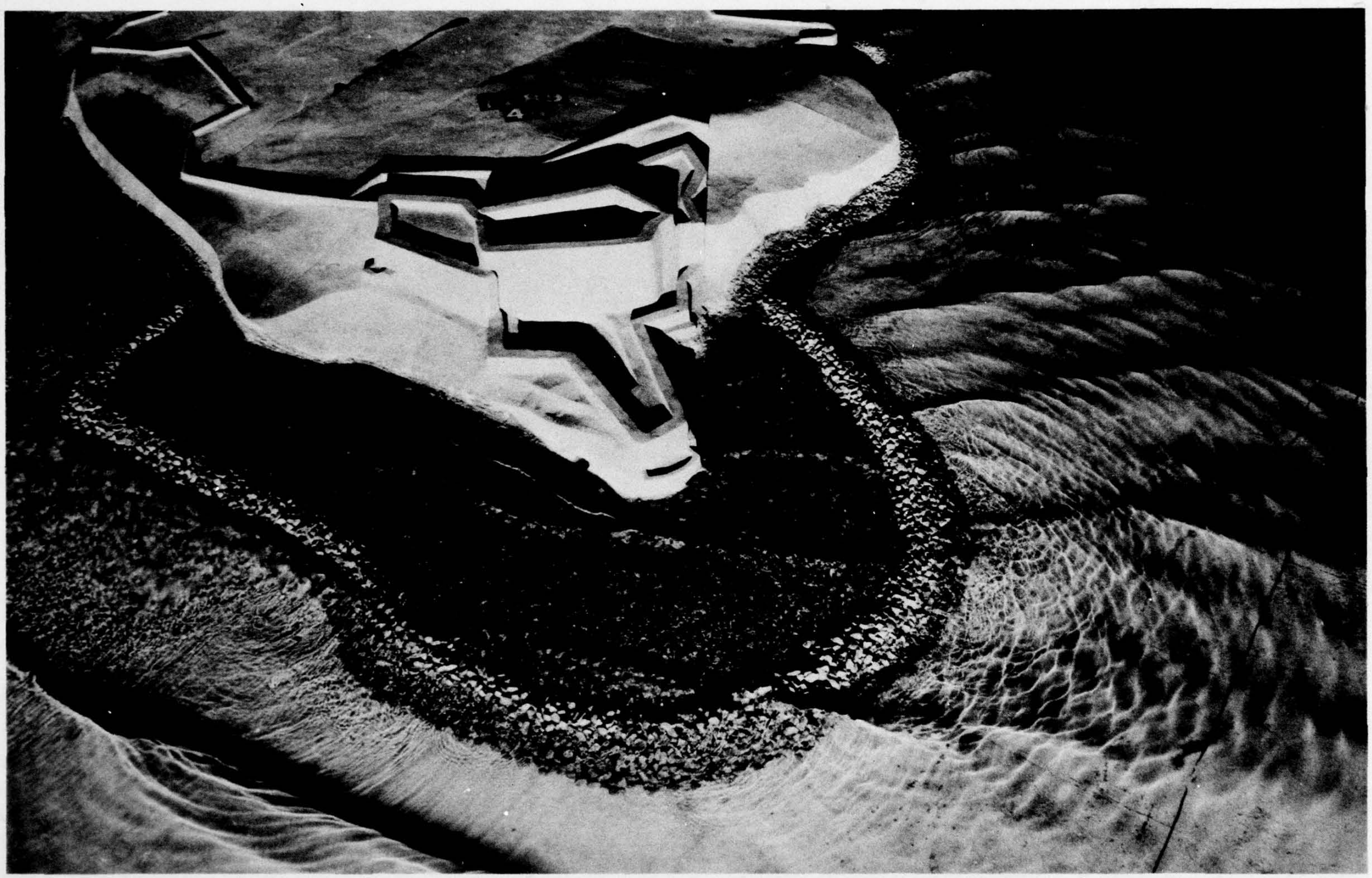


Photo 37. Typical wave patterns for plan 2G; 10-sec, 12-ft waves from north

Photo 38. Typical wave patterns for plan 3D; 10-sec, 12-ft waves from north

Photo 39. Typical wave patterns for plan 4; 10-sec, 12-ft waves from north

Photo 40. Typical wave patterns for plan 5C; 10-sec, 12-ft waves from north

AD-A075 777 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
SAN JUAN NATIONAL HISTORIC SITE, SAN JUAN, PUERTO RICO: DESIGN --ETC(U)
SEP 79 R R BOTTIN
UNCLASSIFIED WES-HL-79-15 NL

2 OF 4
AD
A075777

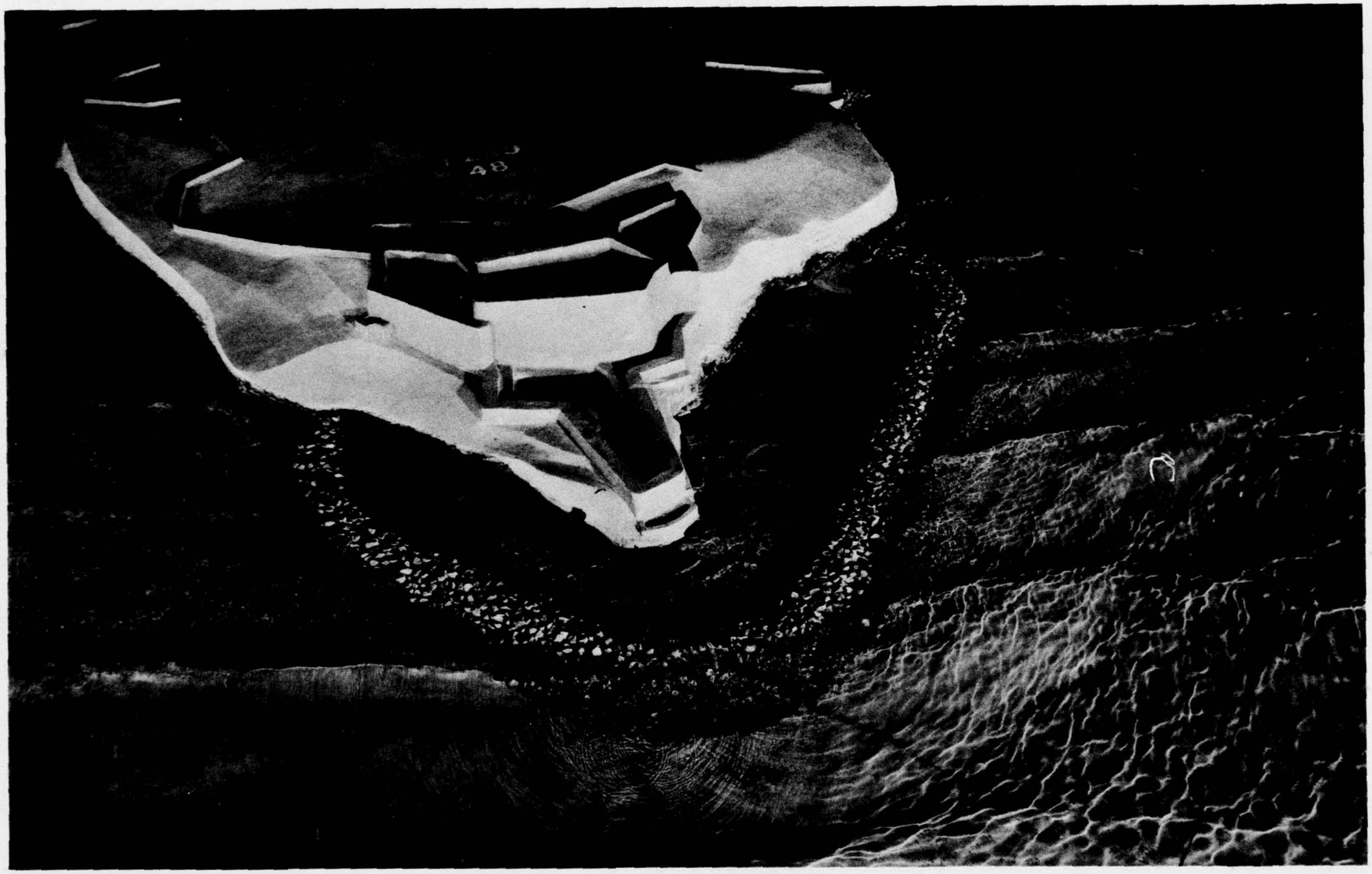


Photo 41. Typical wave patterns for plan 6B; 10-sec, 12-ft waves from northwest

Photo 42. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 5-sec, 6-ft waves from northwest

Photo 43. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 9-sec, 16-ft waves from northwest

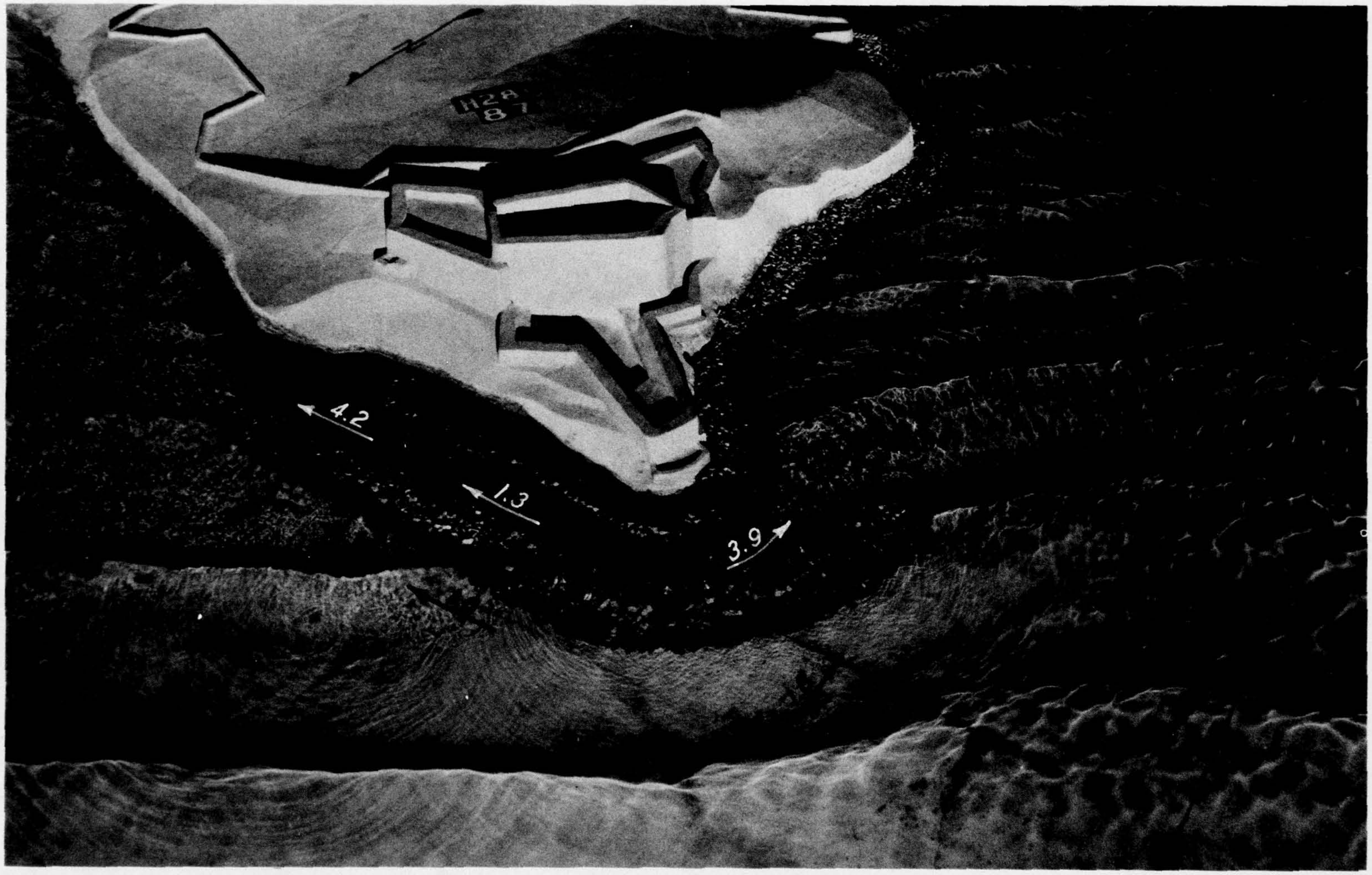


Photo 44. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 10-sec, 12-ft waves from northwest

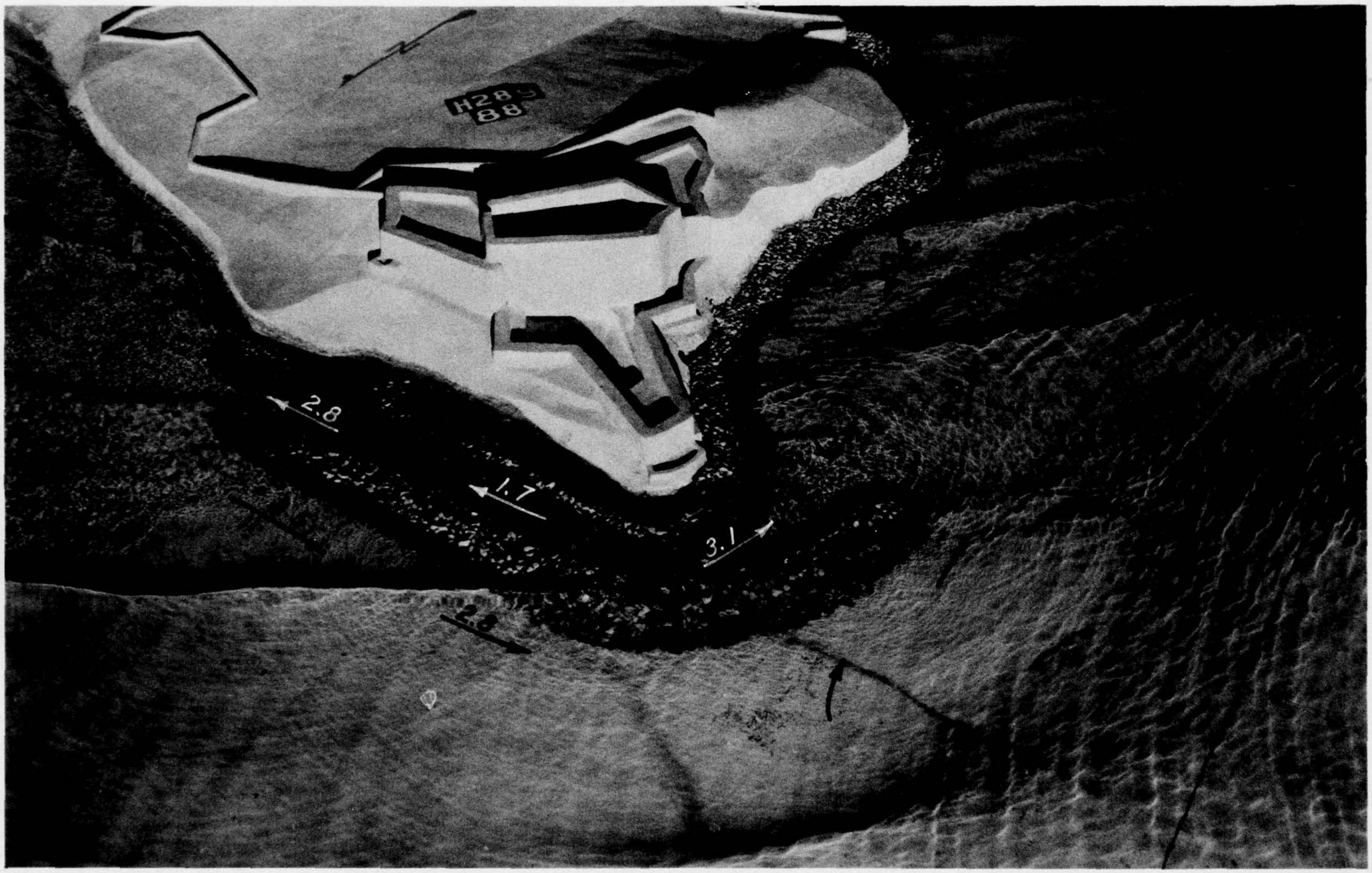


Photo 45. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 13-sec, 8-ft waves from northwest

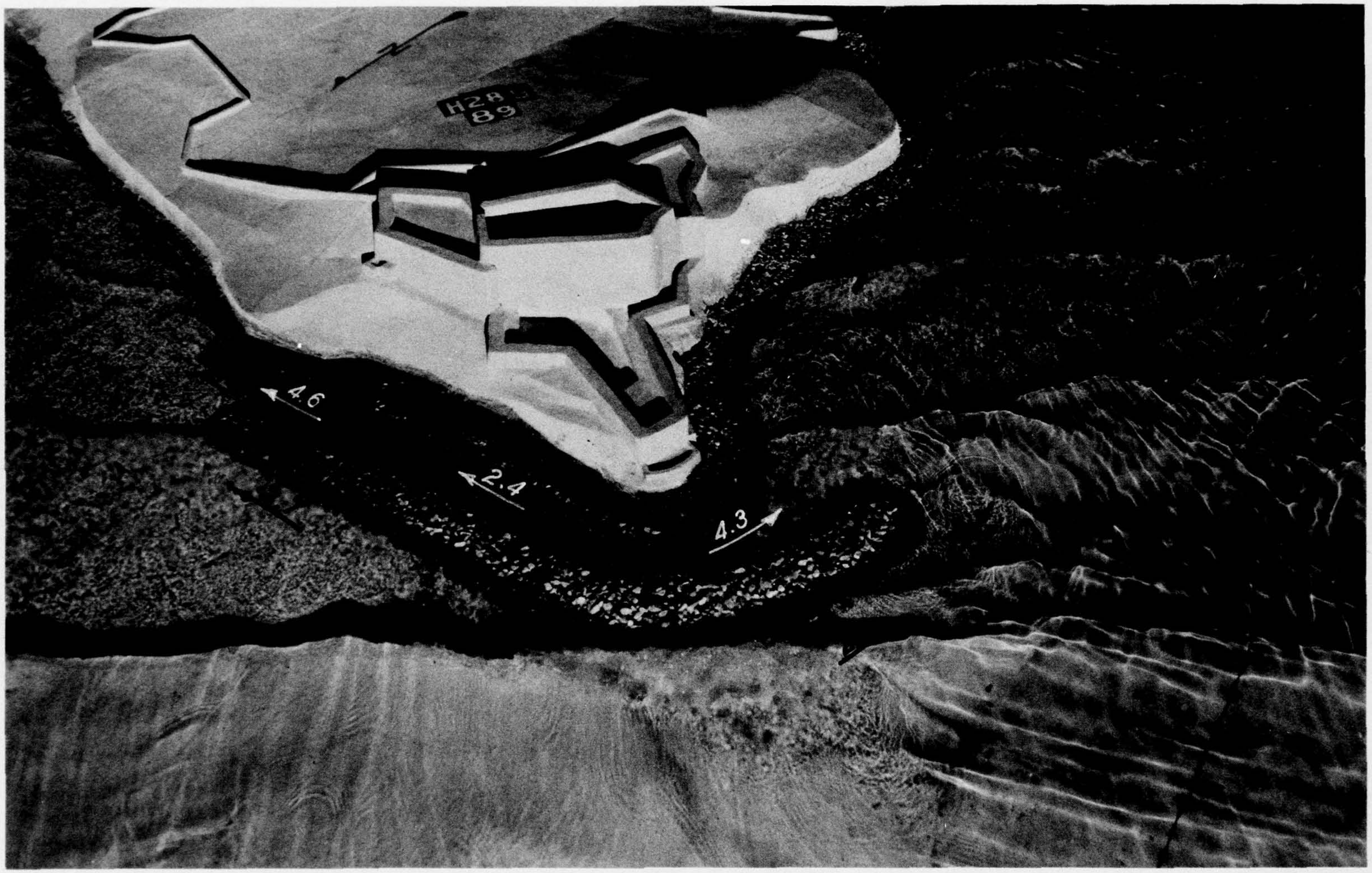


Photo 46. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 13-sec, 16-ft waves from northwest

Photo 47. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 15-sec, 10-ft waves from northwest

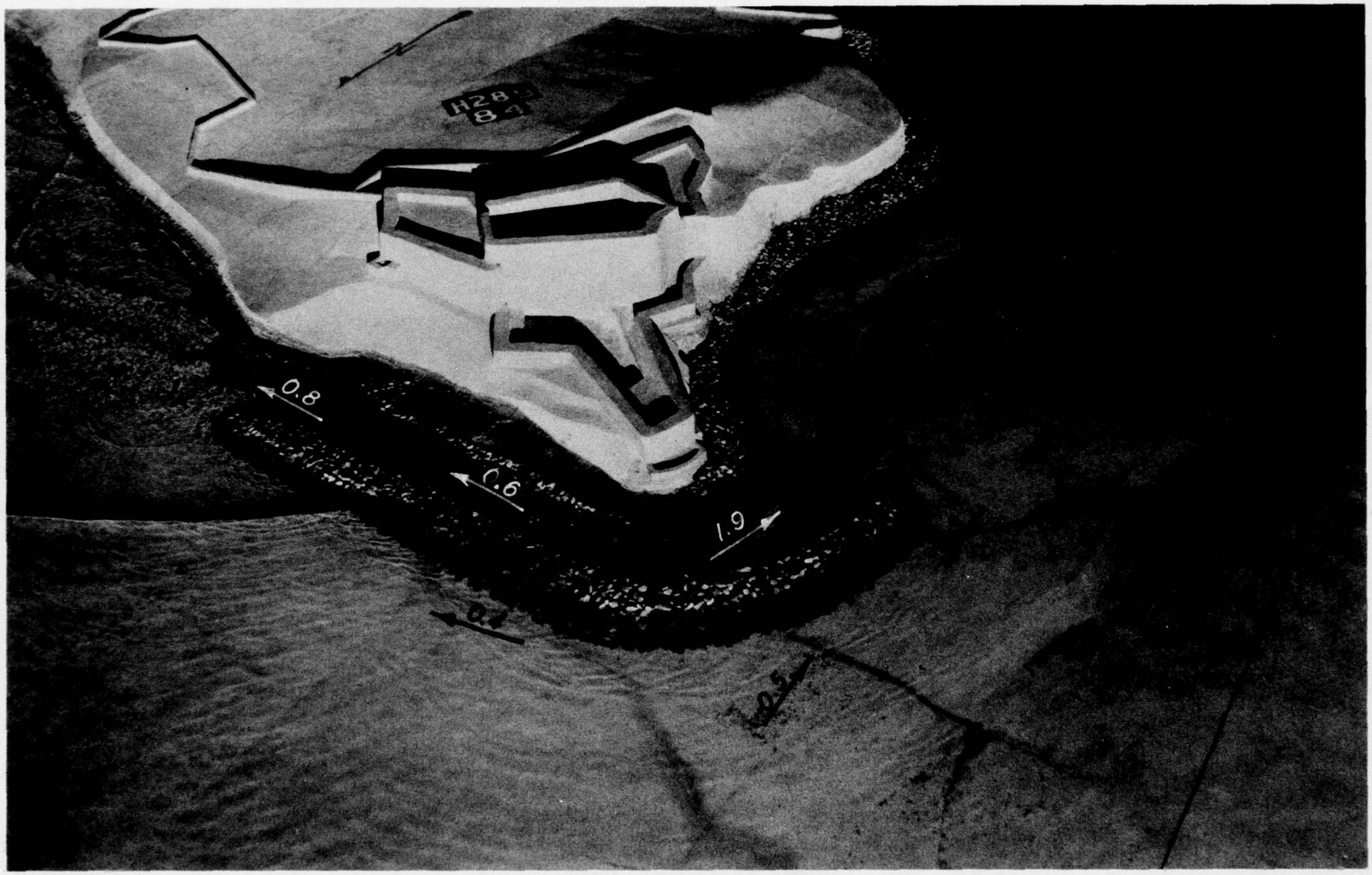


Photo 48. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 19-sec, 4-ft waves from northwest

Photo 49. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 5-sec, 6-ft waves from north

Photo 50. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 9-sec, 22-ft waves from north

Photo 51. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 10-sec, 12-ft waves from north

Photo 52. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 11-sec, 8-ft waves from north

Photo 53. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 11-sec, 16-ft waves from north

Photo 54. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 15-sec, 18-ft waves from north

Photo 55. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 19-sec, 4-ft waves from north

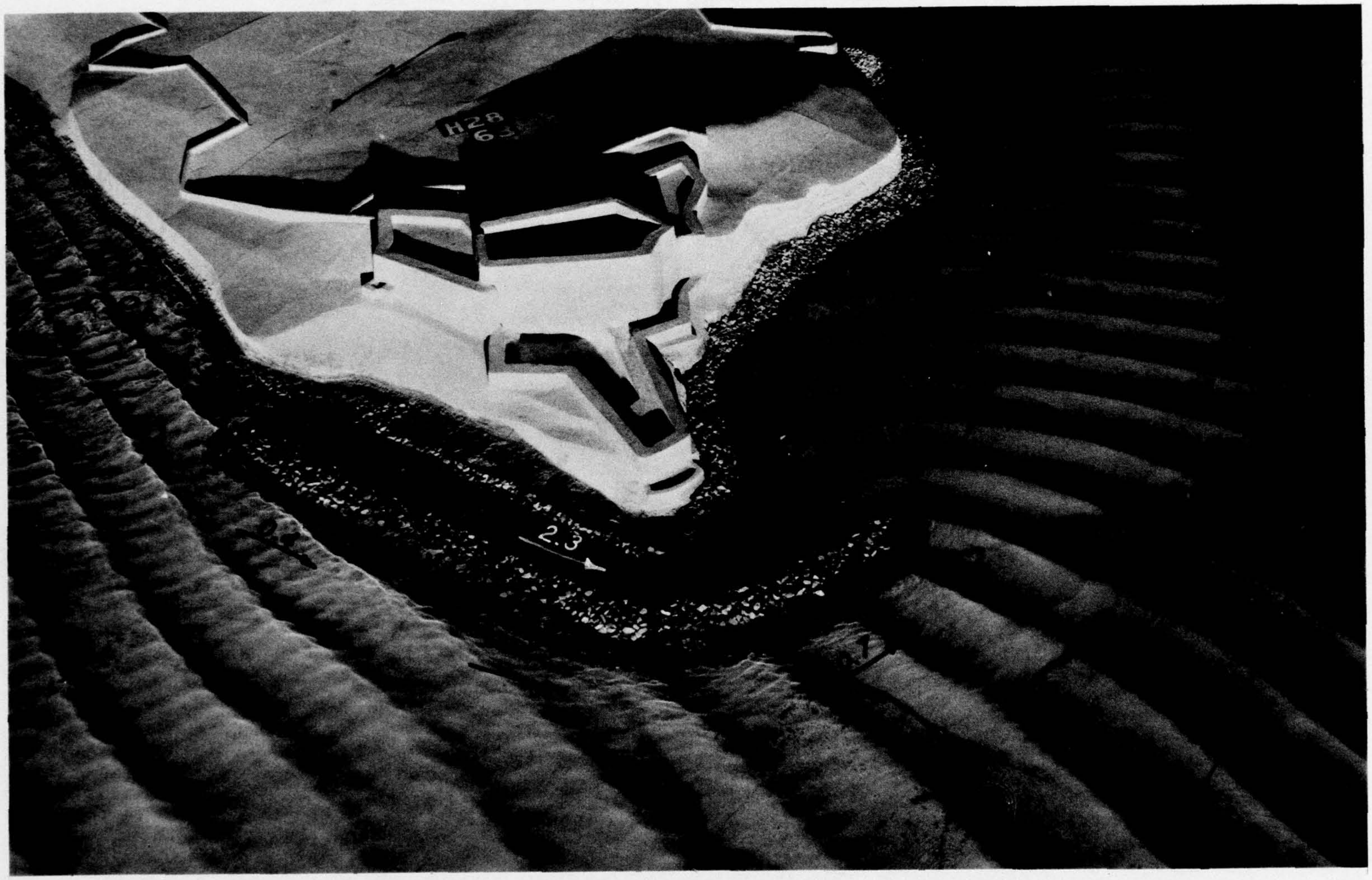


Photo 56. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 5-sec, 6-ft waves from northeast

Photo 57. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 9-sec, 18-ft waves from northeast

Photo 58. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 10-sec, 12-ft waves from northeast

Photo 59. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 11-sec, 10-ft waves from northeast

Photo 60. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 11-sec, 22-ft waves from northeast

Photo 61. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 15-sec, 14-ft waves from northeast

Photo 62. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7A; 19-sec, 6-ft waves from northeast

Photo 63. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 5-sec, 6-ft waves from northwest

Photo 64. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 9-sec, 16-ft waves from northwest

Photo 65. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 10-sec, 12-ft waves from northwest

Photo 66. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 13-sec, 8-ft waves from northwest

Photo 67. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 13-sec, 16-ft waves from northwest

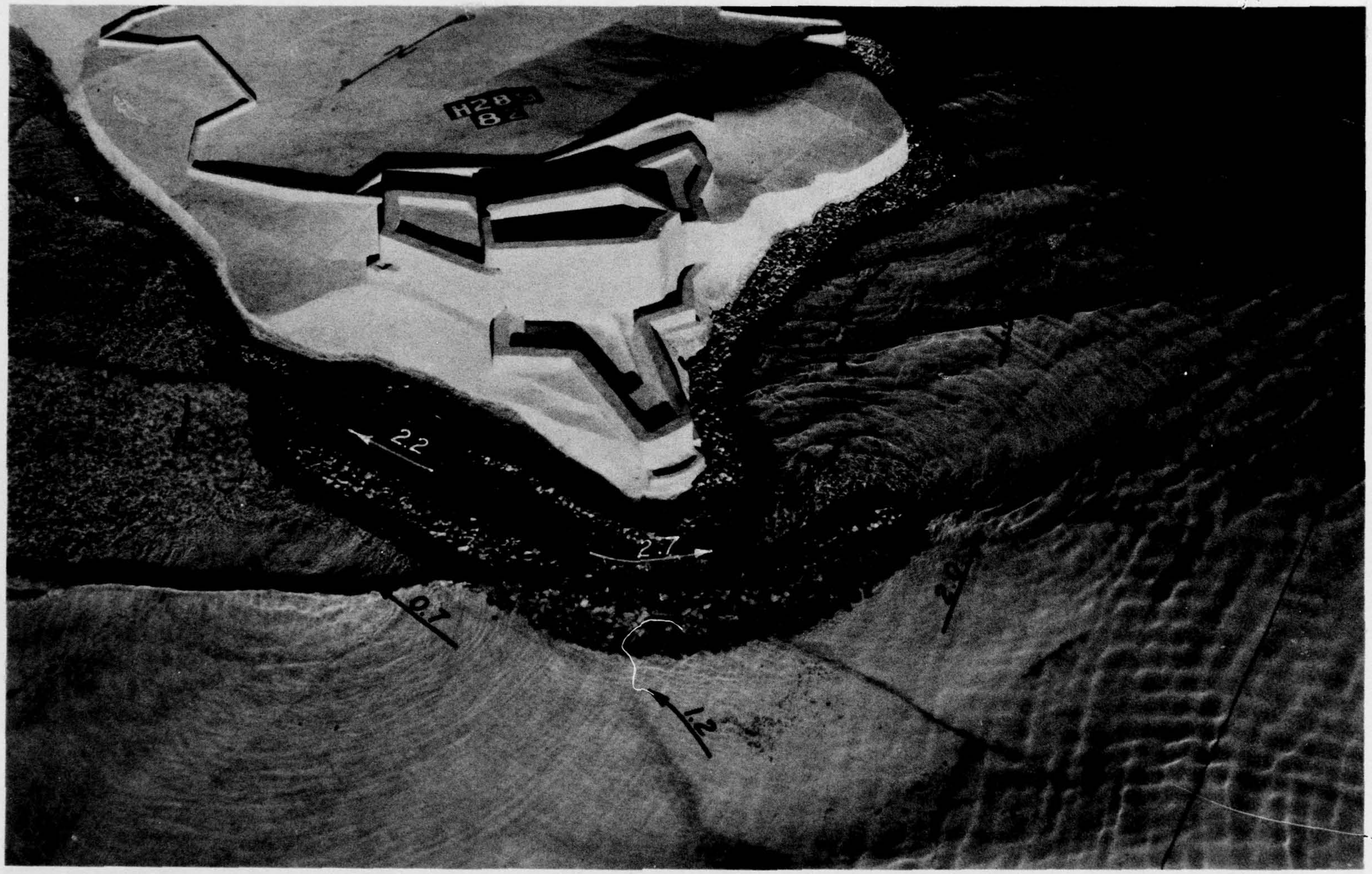


Photo 68. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 15-sec, 10-ft waves from northwest

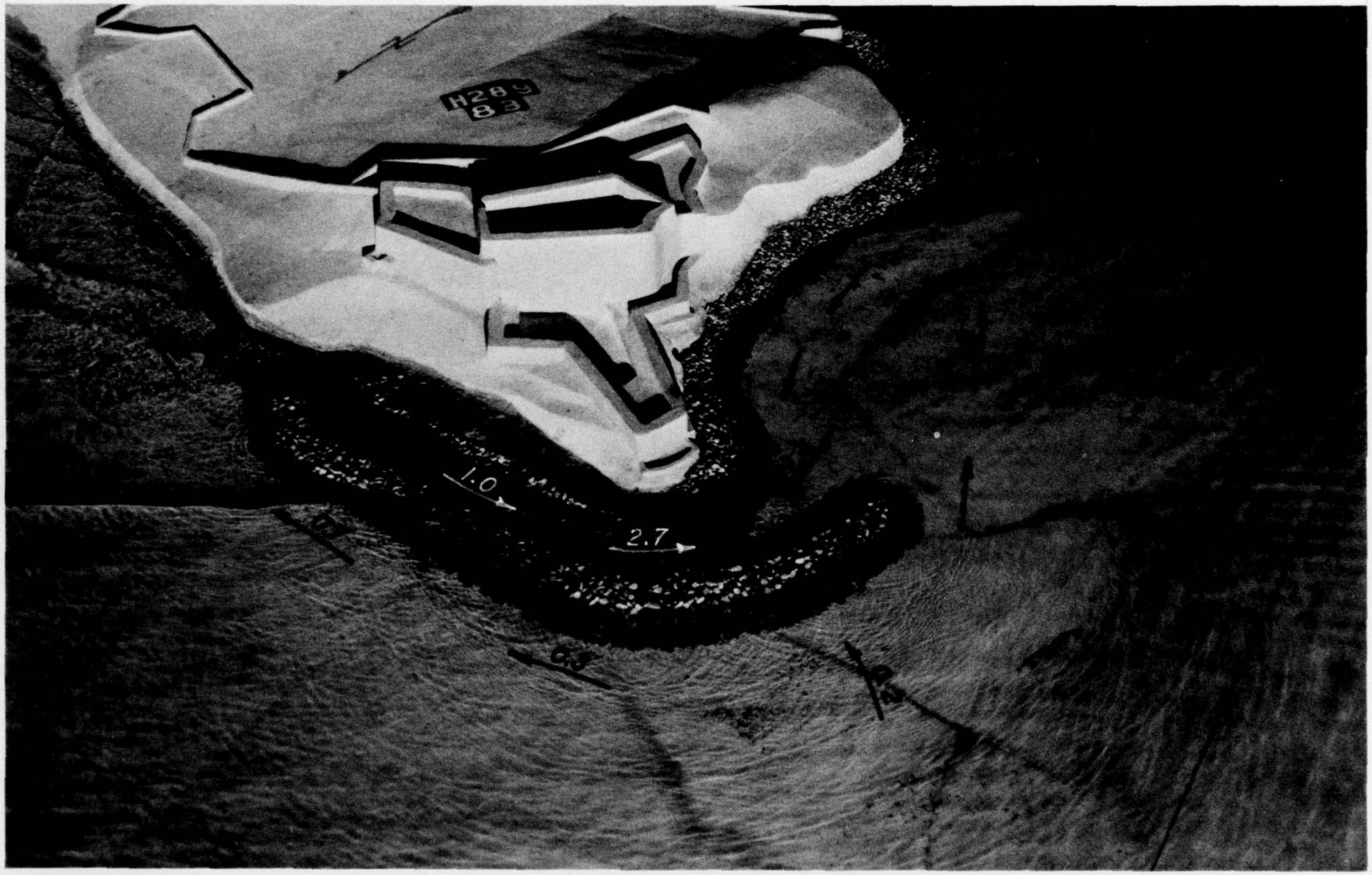


Photo 69. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 19-sec, 4-ft waves from northwest

Photo 70. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 5-sec, 6-ft waves from north

Photo 71. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 9-sec, 22-ft waves from north

Photo 72. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 10-sec, 12-ft waves from north

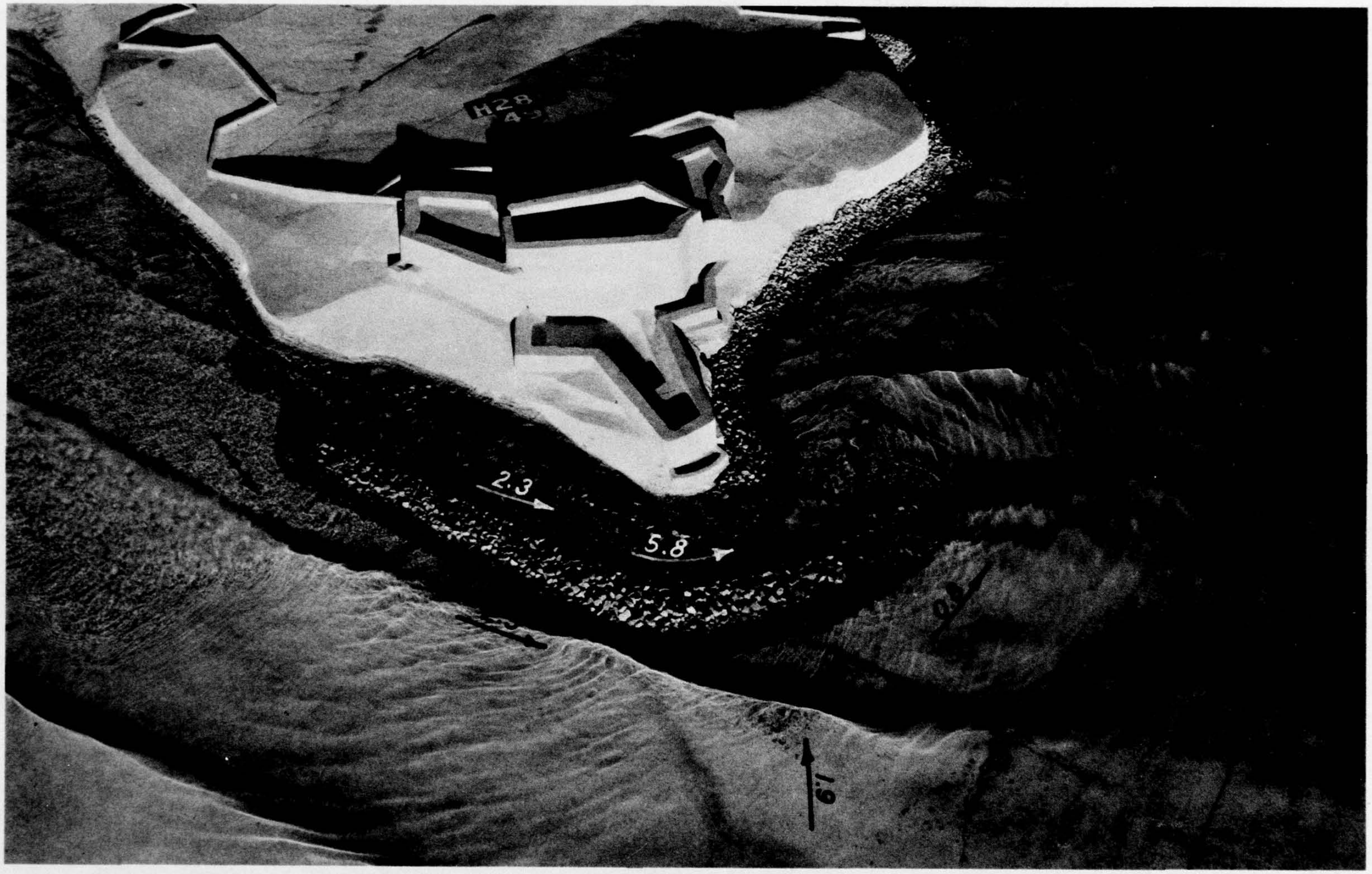


Photo 73. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 11-sec, 8-ft waves from north

Photo 74. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 11-sec, 16-ft waves from north

Photo 75. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 15-sec, 18-ft waves from north

Photo 76. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 19-sec, 4-ft waves from north

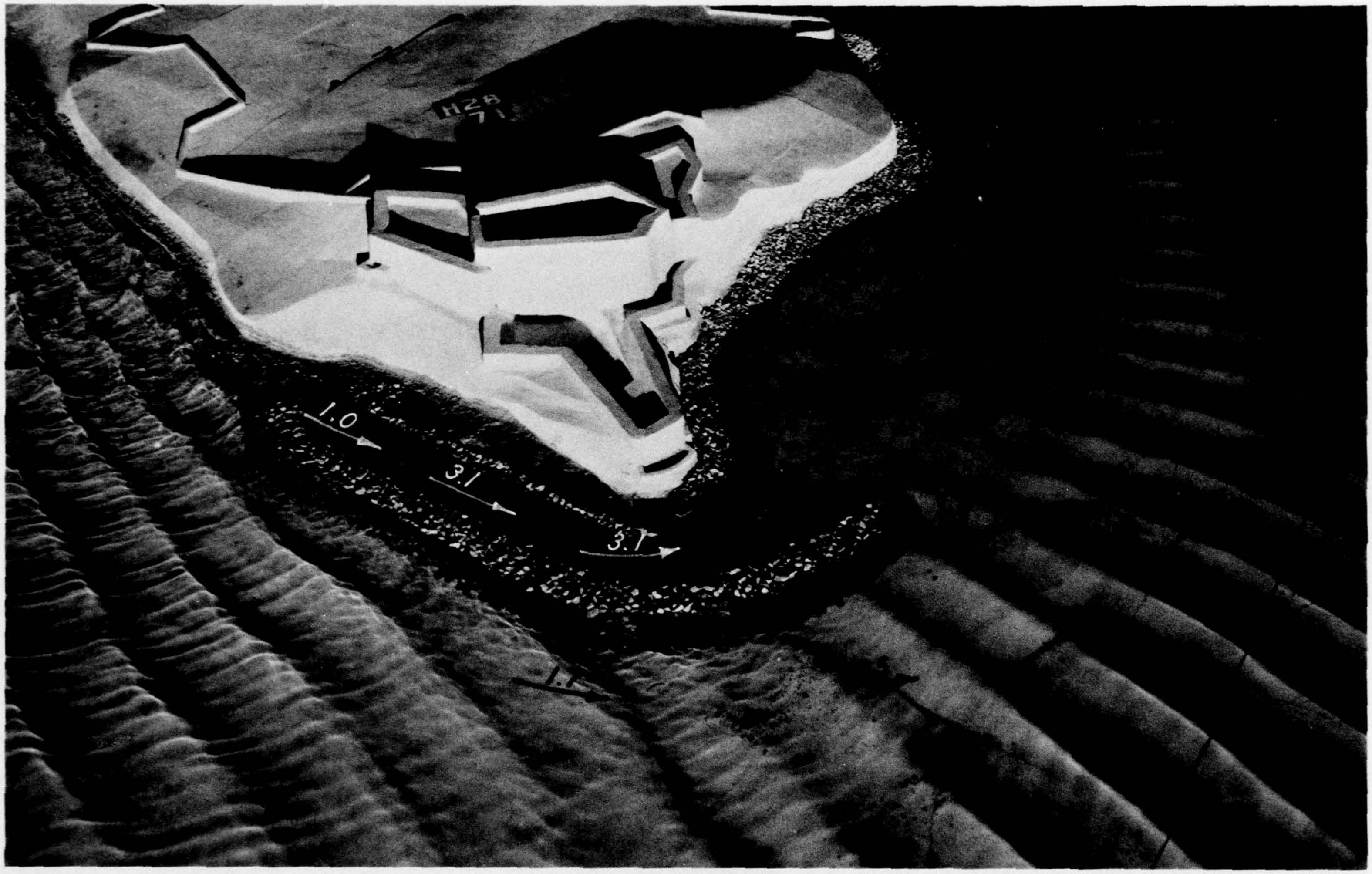


Photo 77. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 5-sec, 6-ft waves from northeast

Photo 78. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 9-sec, 18-ft waves from northeast

Photo 79. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 10-sec, 12-ft waves from northeast

Photo 80. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 11-sec, 10-ft waves from northeast

Photo 81. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 11-sec, 22-ft waves from northeast

Photo 82. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 15-sec, 14-ft waves from northeast

Photo 83. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for plan 7B; 19-sec, 6-ft waves from northeast

Photo 84. Typical wave patterns for plan 7C; 10-sec, 12-ft waves from northwest

Photo 85. Typical wave patterns for plan 7C; 10-sec, 12-ft waves from north

Photo 86. Typical wave patterns for plan 7C; 10-sec, 12-ft waves from northeast

Photo 87. Typical wave patterns for plan 7D; 10-sec, 12-ft waves from northwest

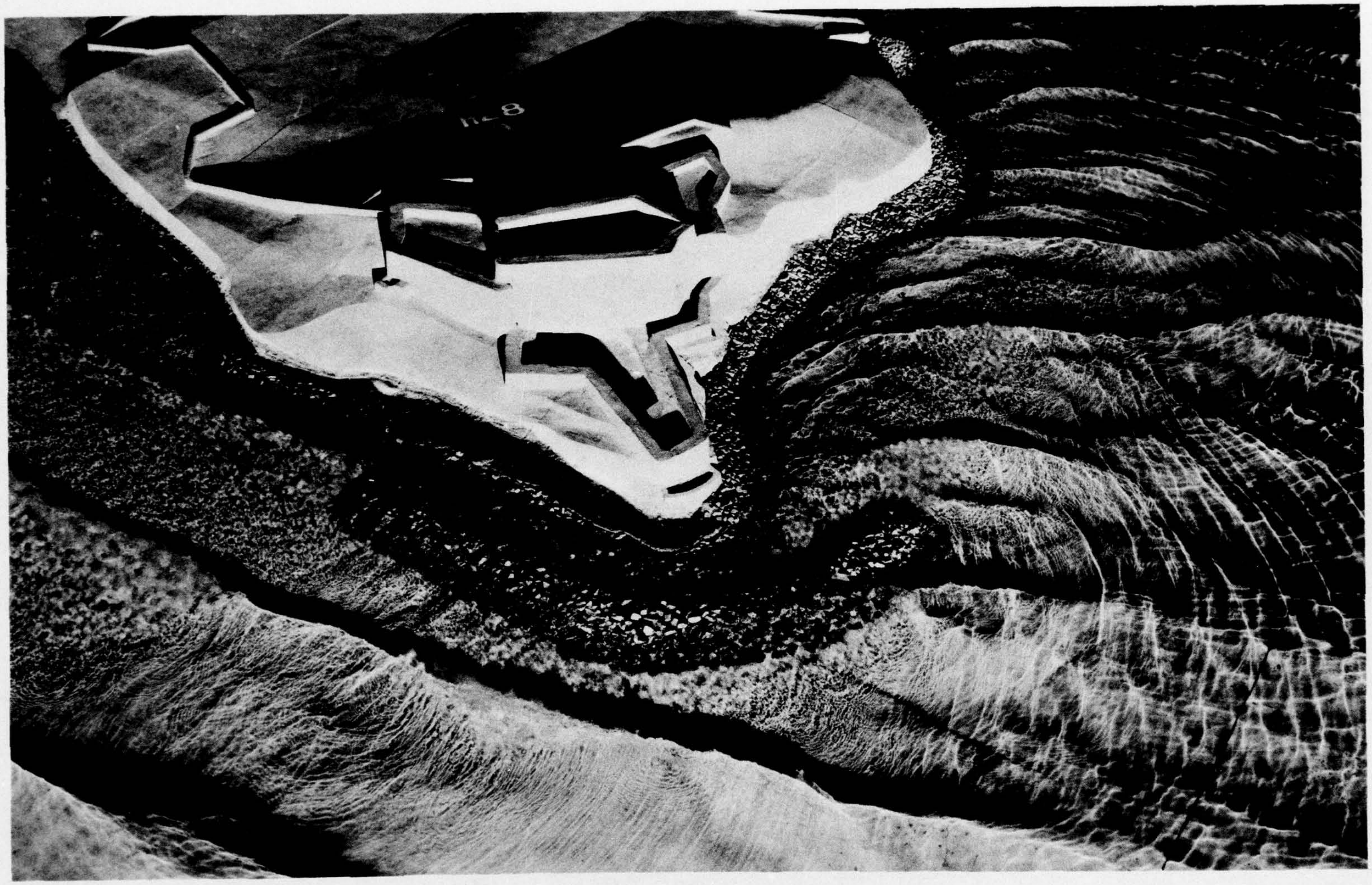


Photo 88. Typical wave patterns for plan 7D; 10-sec, 12-ft waves from north

Photo 89. Typical wave patterns for plan 7D; 10-sec, 12-ft waves from northeast

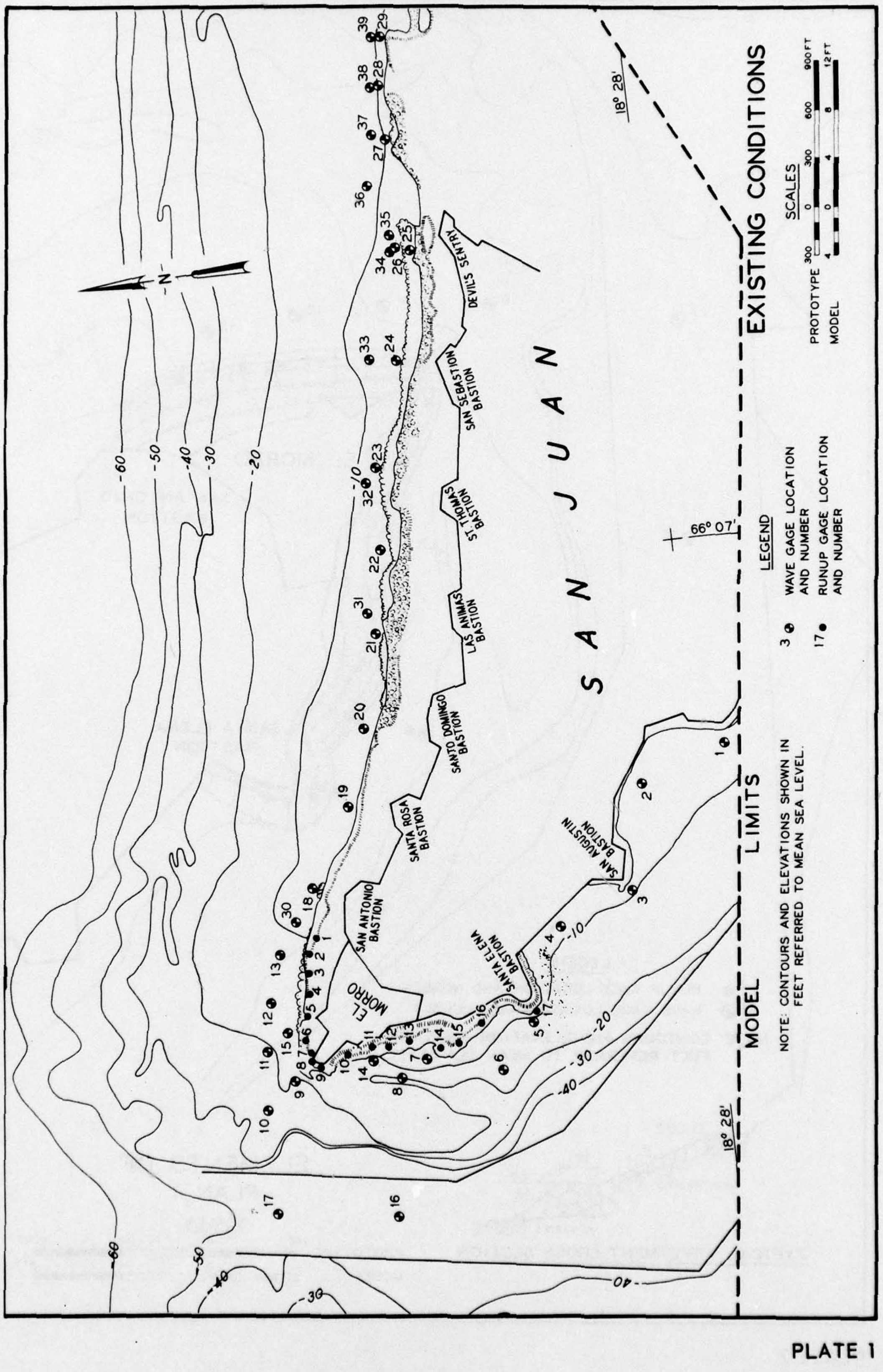
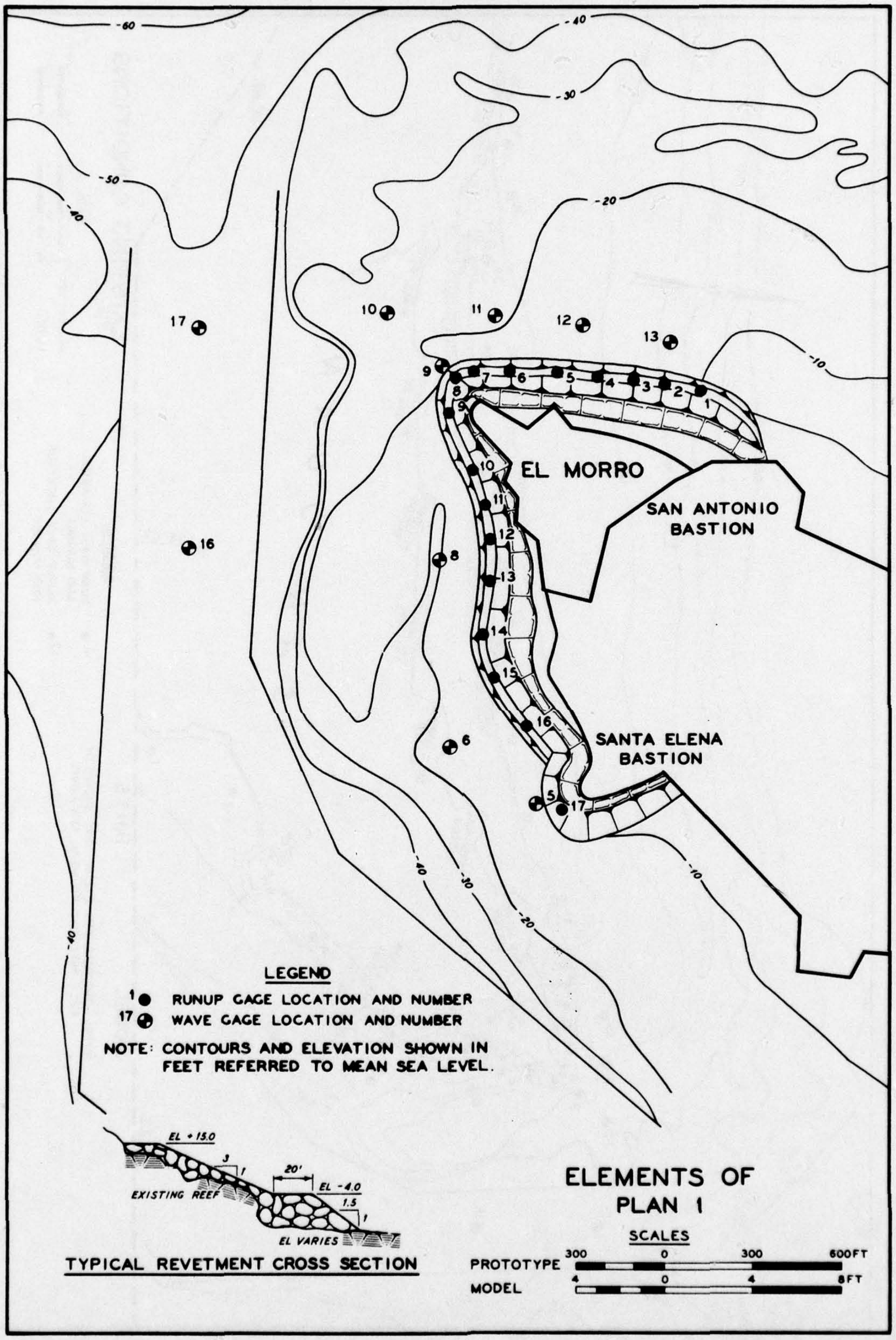

EXISTING CONDITIONS
SAN JUAN
MODEL LIMITS
NOTE: CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN SEA LEVEL.
LEGEND
WAVE GAGE LOCATION AND NUMBER
RUNUP GAGE LOCATION AND NUMBER
SCALES
PROTOTYPE 300 0 300 600 900 FT
MODEL 4 0 4 8 12 FT
EL MORRO
SAN ANTONIO BASTION
SANTA ROSA BASTION
SANTO DOMINGO BASTION
LAS ANIMAS BASTION
ST. THOMAS BASTION
SAN SEBASTION BASTION
DEVIL'S SENTRY
SANTA ELENA BASTION
SAN AGUSTIN BASTION
N
18° 28'
66° 07'

PLATE 1


-60
-40
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-40
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-10
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3
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1
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14
15
16
5
17
16
8
6
EL MORRO
SAN ANTONIO
BASTION
SANTA ELENA
BASTION
-40
-30
-20
-10
-40
LEGEND
1 RUNUP GAGE LOCATION AND NUMBER
17 WAVE GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN
FEET REFERRED TO MEAN SEA LEVEL.
EL +15.0
3
1
20'
EL -4.0
1.5
1
EXISTING REEF
EL VARIES
TYPICAL REVETMENT CROSS SECTION
ELEMENTS OF
PLAN 1
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT

PLATE 2

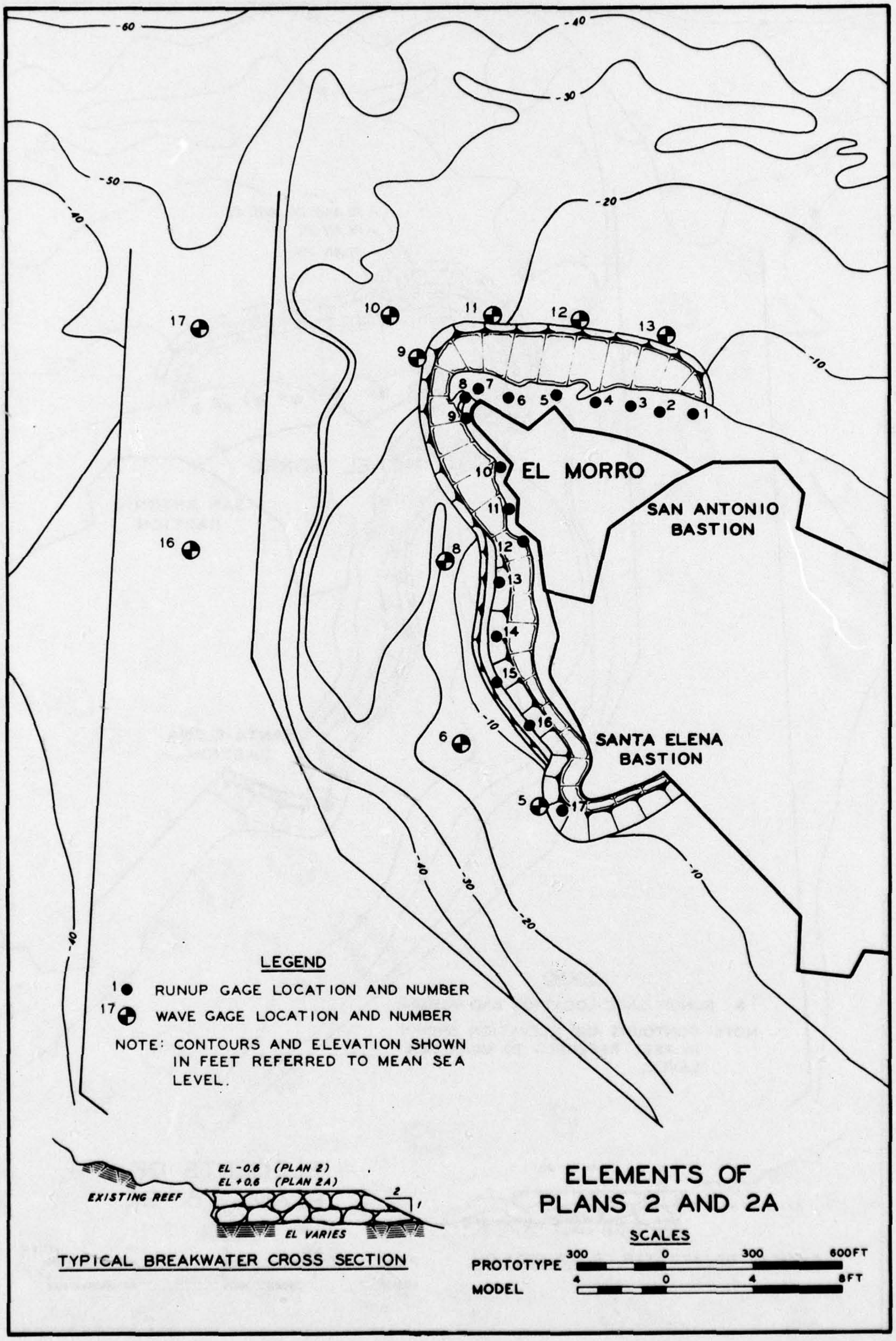

-60
-40
-30
-50
-40
-20
-10
EL MORRO
SAN ANTONIO BASTION
SANTA ELENA BASTION
-10
-40
-30
-20
-10
-40
LEGEND
RUNUP GAGE LOCATION AND NUMBER
WAVE GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN FEET REFERRED TO MEAN SEA LEVEL.
EL -0.6 (PLAN 2)
EL +0.6 (PLAN 2A)
EXISTING REEF
EL VARIES
TYPICAL BREAKWATER CROSS SECTION
ELEMENTS OF PLANS 2 AND 2A
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT

PLATE 3

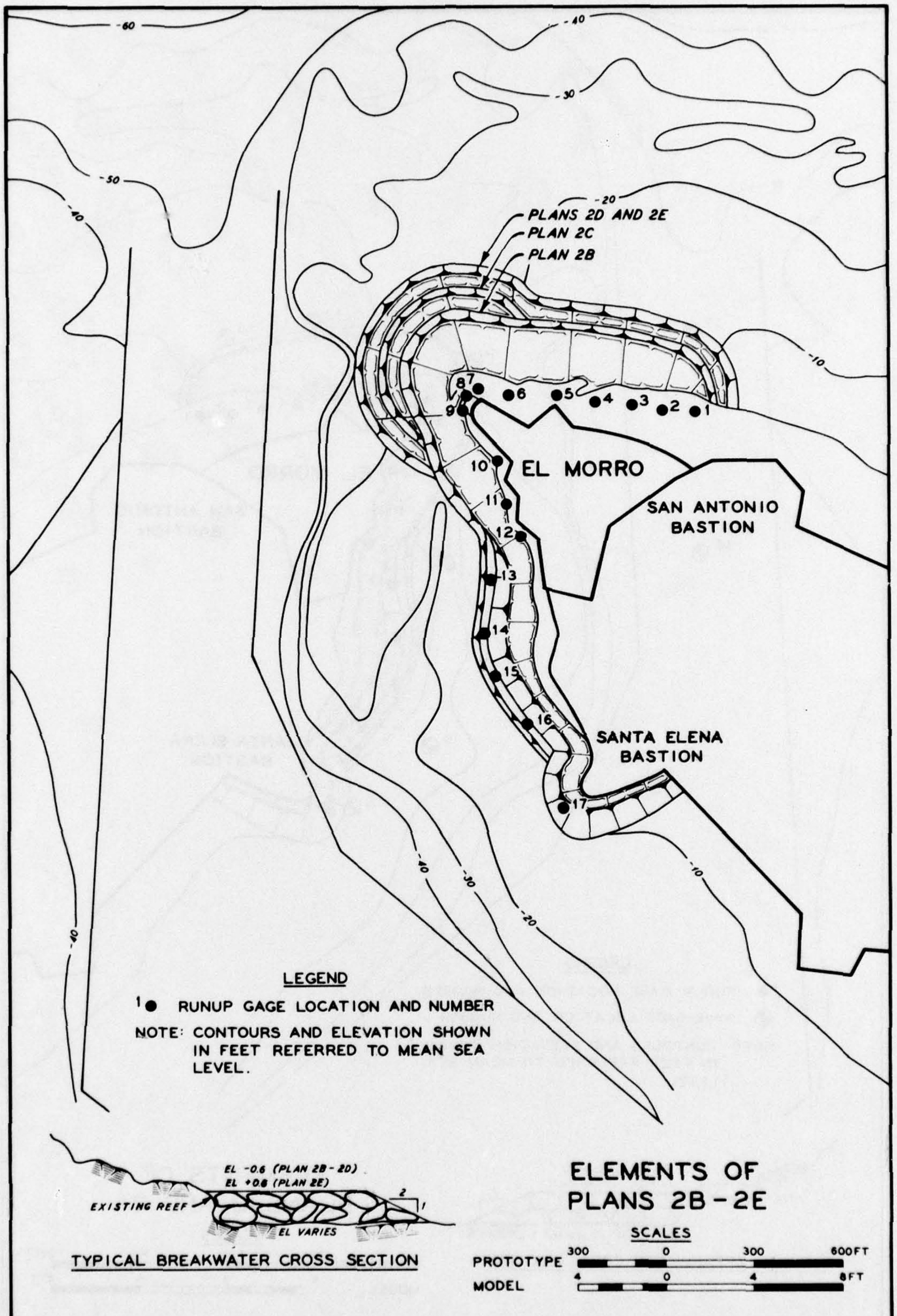
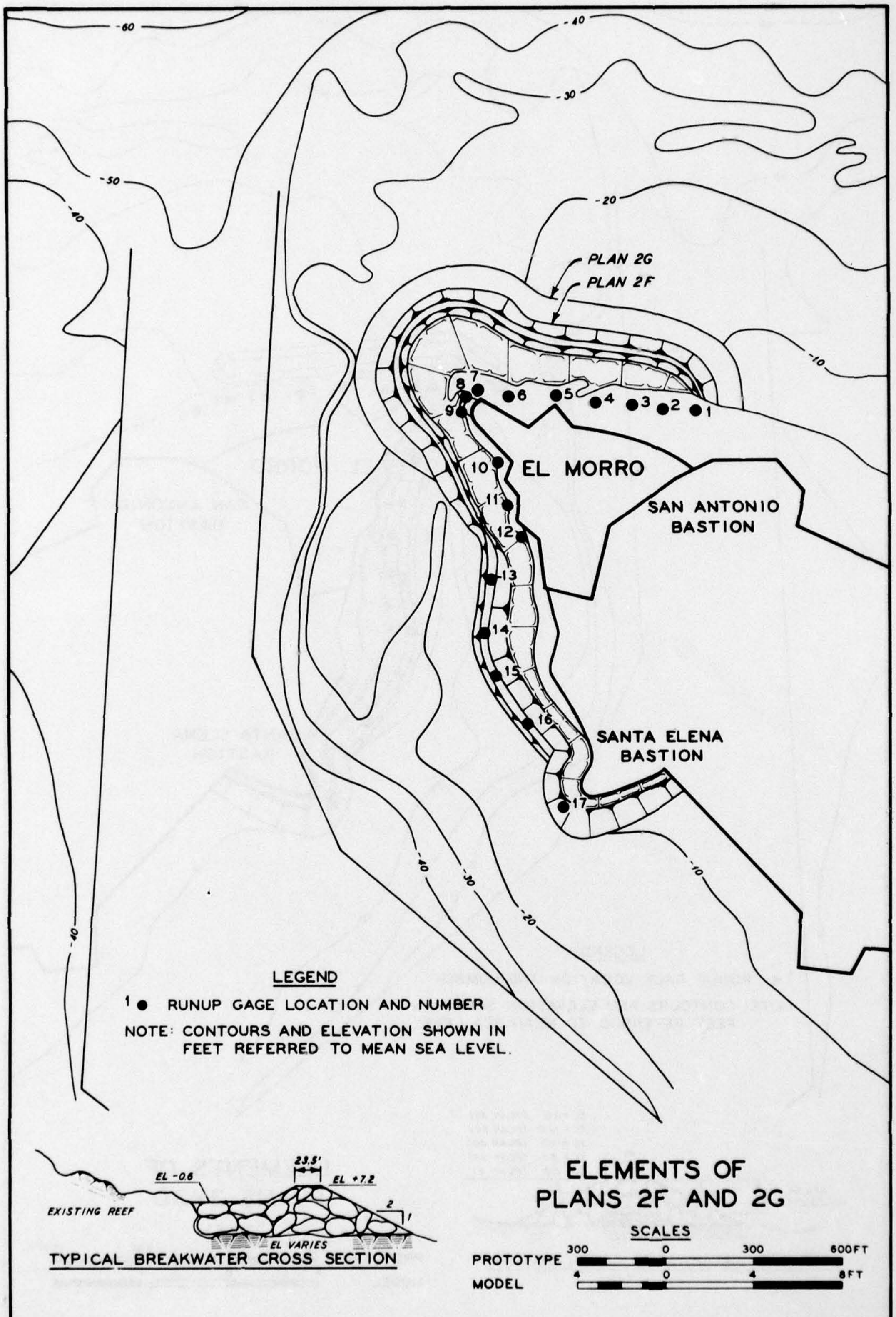

-60
-40
-30
-50
-40
-20
-10
PLANS 2D AND 2E
PLAN 2C
PLAN 2B
8
7
6
5
4
3
2
1
9
10
EL MORRO
11
SAN ANTONIO
BASTION
12
13
14
15
16
SANTA ELENA
BASTION
17
-10
-40
-30
-20
-40
LEGEND
1 RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN
IN FEET REFERRED TO MEAN SEA
LEVEL.
EL -0.6 (PLAN 2B - 2D)
EL +08 (PLAN 2E)
EXISTING REEF
EL VARIES
2
1
TYPICAL BREAKWATER CROSS SECTION
ELEMENTS OF
PLANS 2B - 2E
SCALES
PROTOTYPE
300 0 300 600FT
MODEL
4 0 4 8FT

PLATE 4



ELEMENTS OF PLANS 2F AND 2G

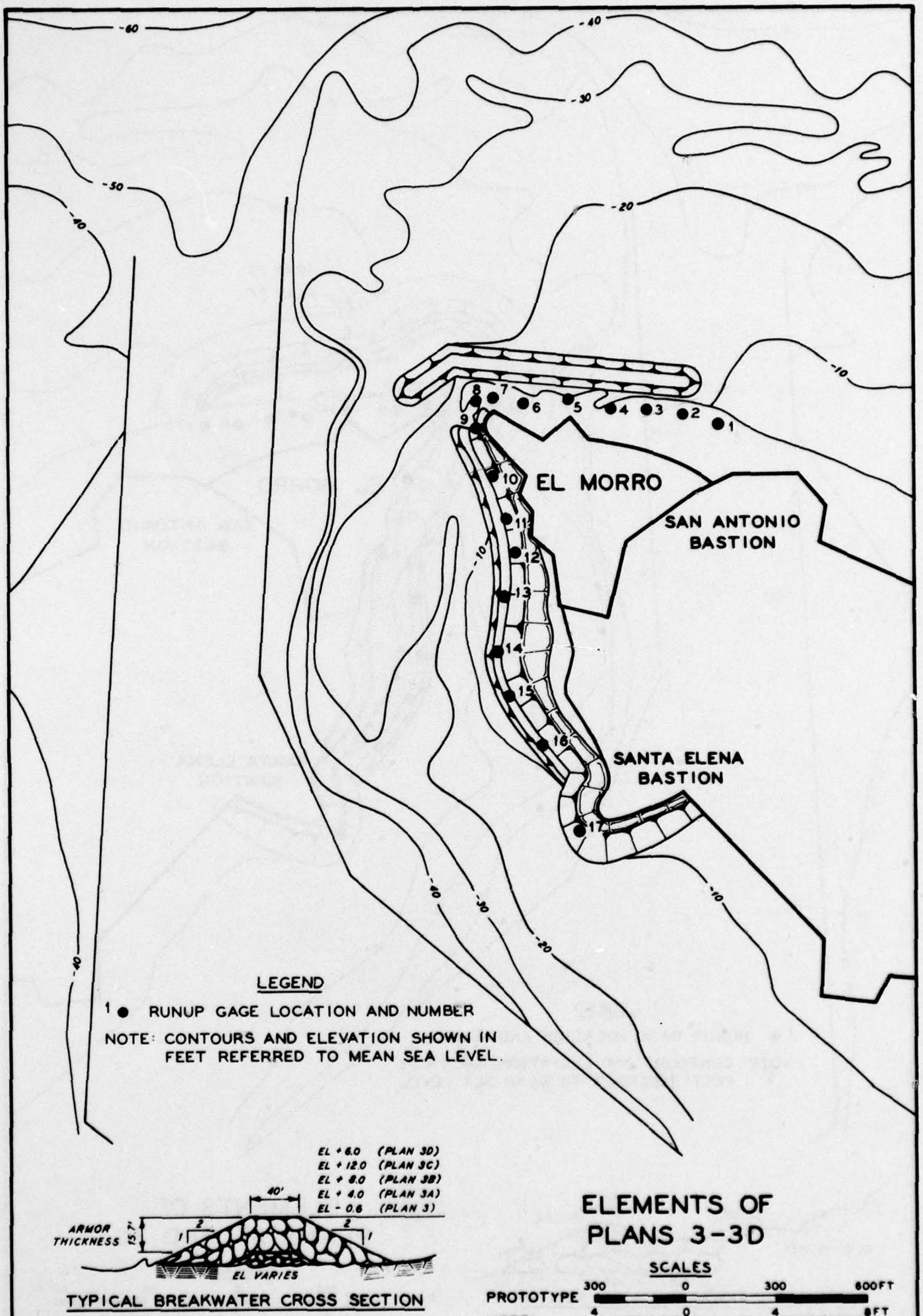
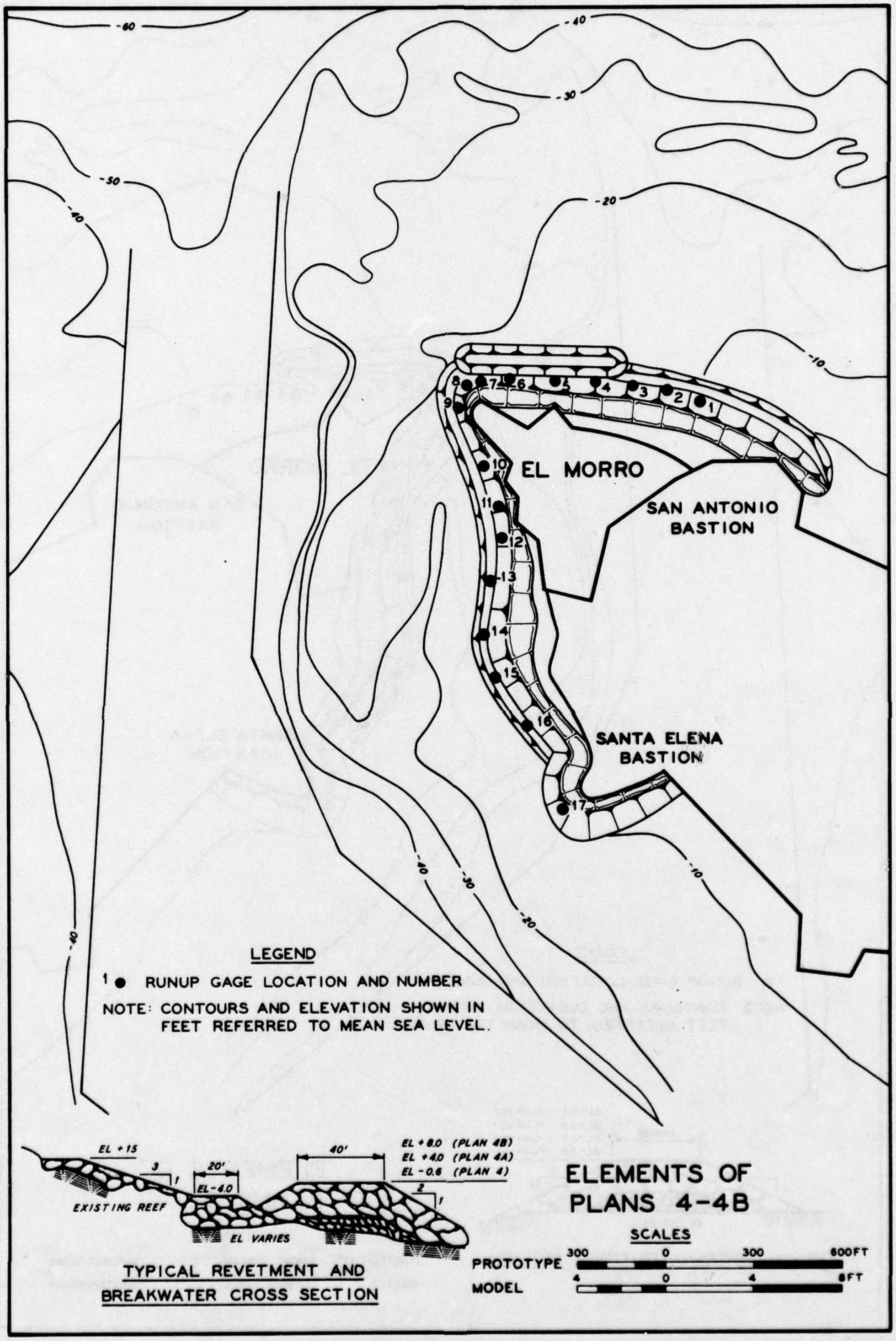

-60
-50
-40
-30
-20
-10
EL MORRO
SAN ANTONIO BASTION
SANTA ELENA BASTION
LEGEND
1 ● RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN FEET REFERRED TO MEAN SEA LEVEL.
EL + 6.0 (PLAN 3D)
EL + 12.0 (PLAN 3C)
EL + 8.0 (PLAN 3B)
EL + 4.0 (PLAN 3A)
EL - 0.6 (PLAN 3)
40'
ARMOR THICKNESS
15.7'
EL VARIES
TYPICAL BREAKWATER CROSS SECTION
ELEMENTS OF PLANS 3-3D
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT

PLATE 6



EL MORRO
SAN ANTONIO BASTION
SANTA ELENA BASTION
LEGEND
1 ● RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN FEET REFERRED TO MEAN SEA LEVEL.
EL + 15
EXISTING REEF
20'
EL -4.0
40'
EL + 8.0 (PLAN 4B)
EL + 4.0 (PLAN 4A)
EL - 0.6 (PLAN 4)
EL VARIES
TYPICAL REVETMENT AND BREAKWATER CROSS SECTION
ELEMENTS OF PLANS 4-4B
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT

PLATE 7

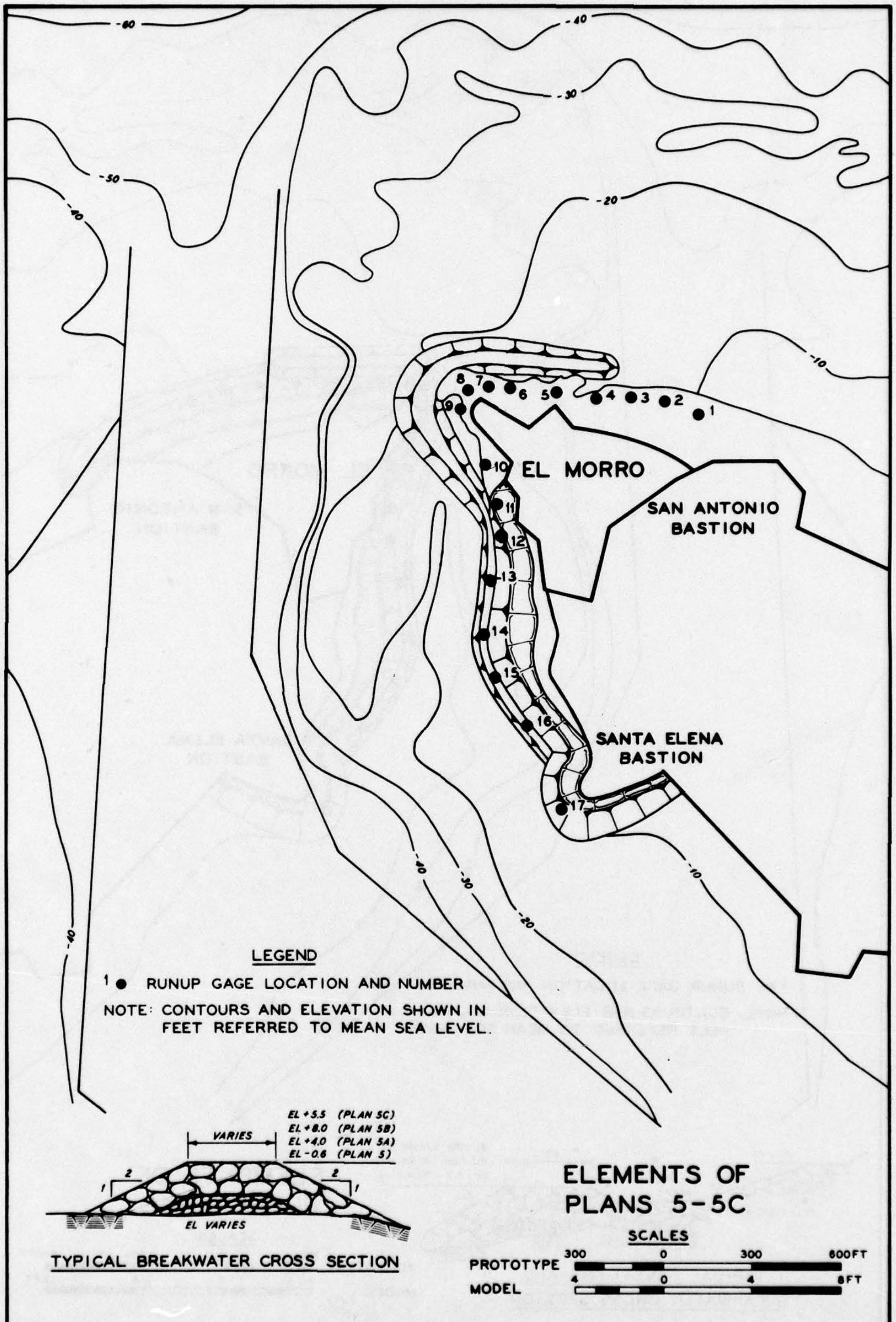
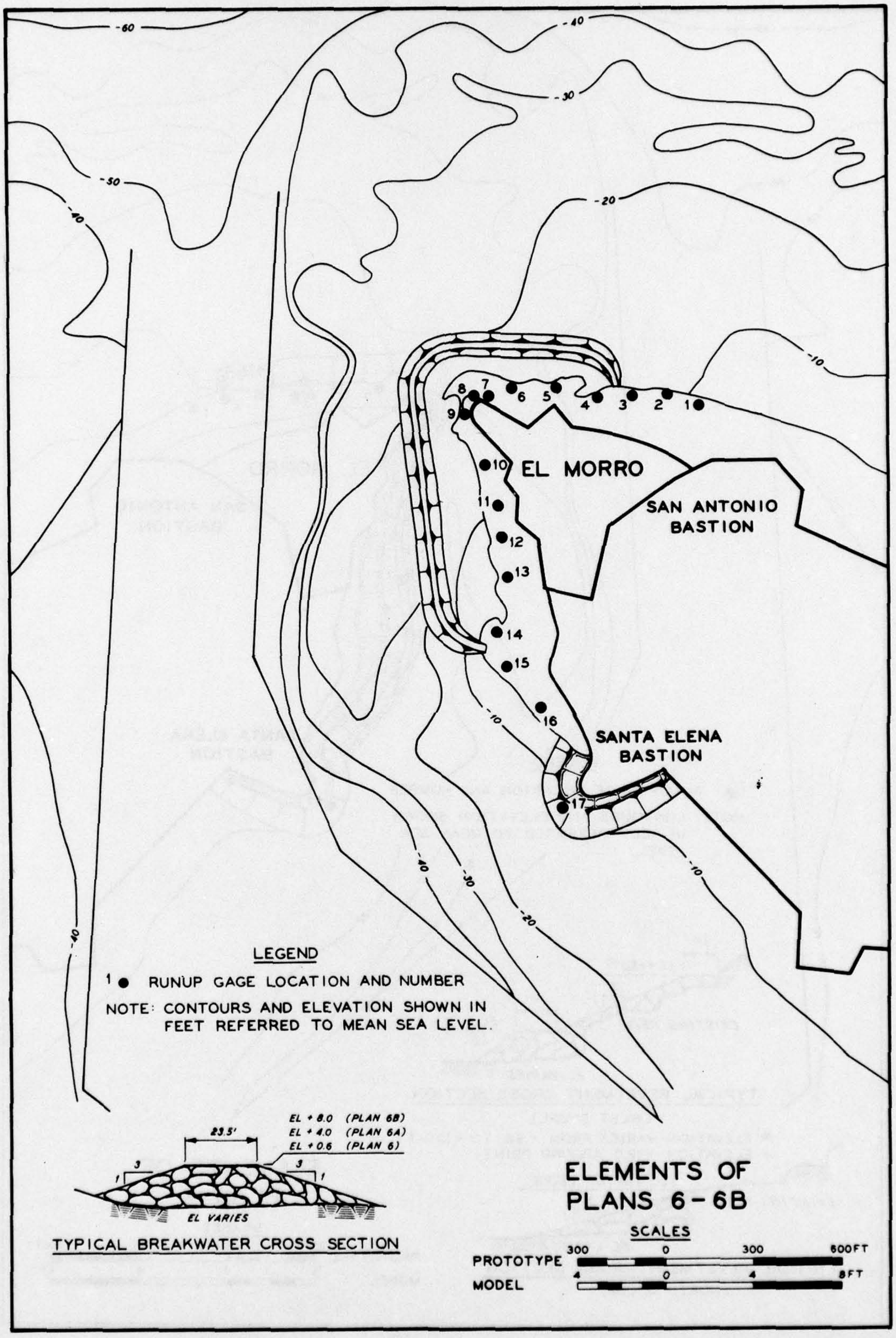

-60
-40
-30
-50
-40
-20
-10
8 7 6 5 4 3 2 1
9
10
EL MORRO
SAN ANTONIO
BASTION
11
12
13
14
15
16
SANTA ELENA
BASTION
17
-10
-40
-30
-20
-40
LEGEND
1 ● RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN FEET REFERRED TO MEAN SEA LEVEL.
VARIES
EL +5.5 (PLAN 5C)
EL +8.0 (PLAN 5B)
EL +4.0 (PLAN 5A)
EL -0.6 (PLAN 5)
2
1
EL VARIES
TYPICAL BREAKWATER CROSS SECTION
ELEMENTS OF
PLANS 5-5C
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT

PLATE 8


-60
-40
-30
-50
-40
-20
-10
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
EL MORRO
SAN ANTONIO
BASTION
SANTA ELENA
BASTION
-10
-40
-30
-20
-10
-40
LEGEND
1 ● RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN
FEET REFERRED TO MEAN SEA LEVEL.
23.5'
EL + 8.0 (PLAN 6B)
EL + 4.0 (PLAN 6A)
EL + 0.6 (PLAN 6)
3
1
3
1
EL VARIES
TYPICAL BREAKWATER CROSS SECTION
ELEMENTS OF
PLANS 6 - 6B
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT

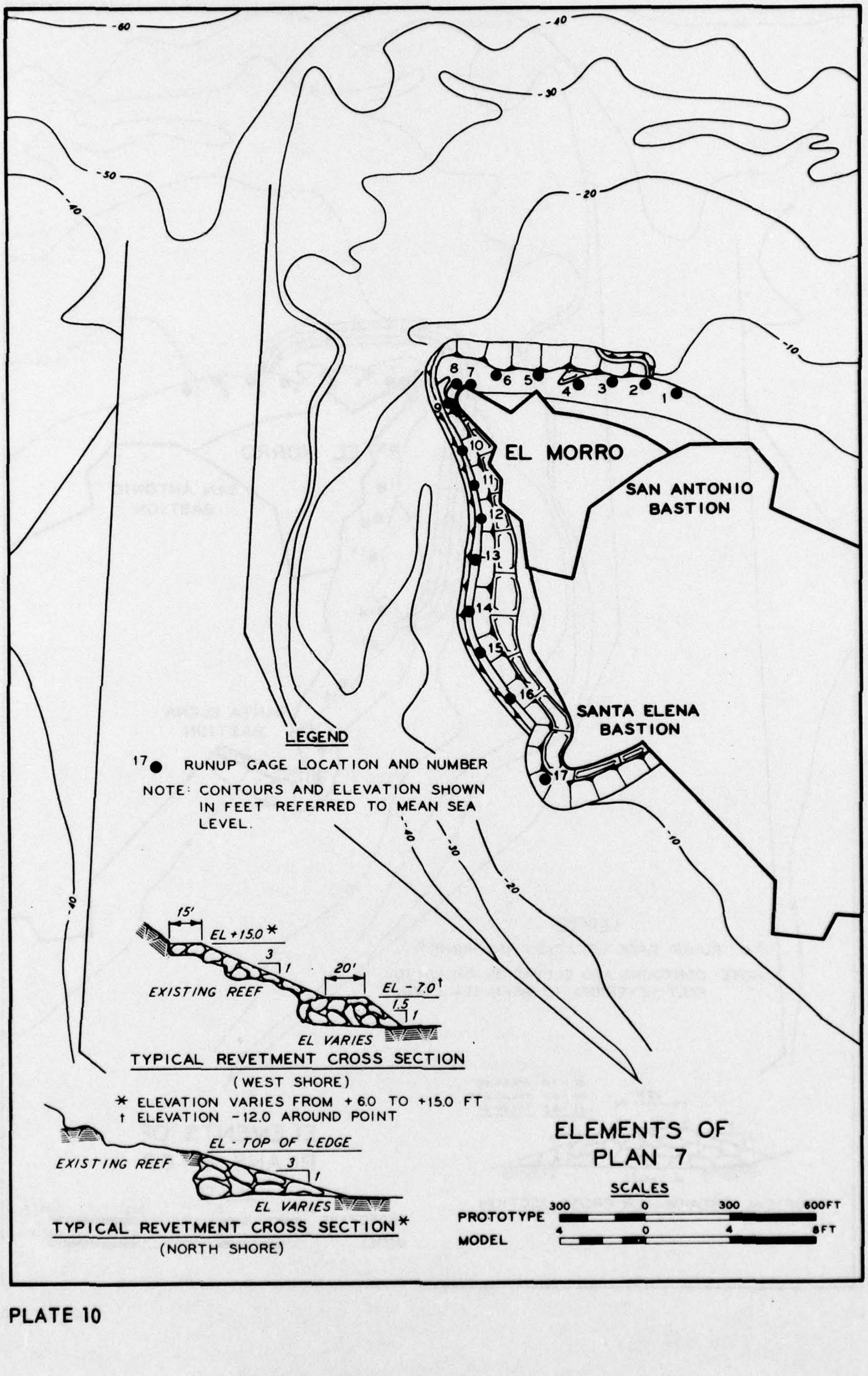
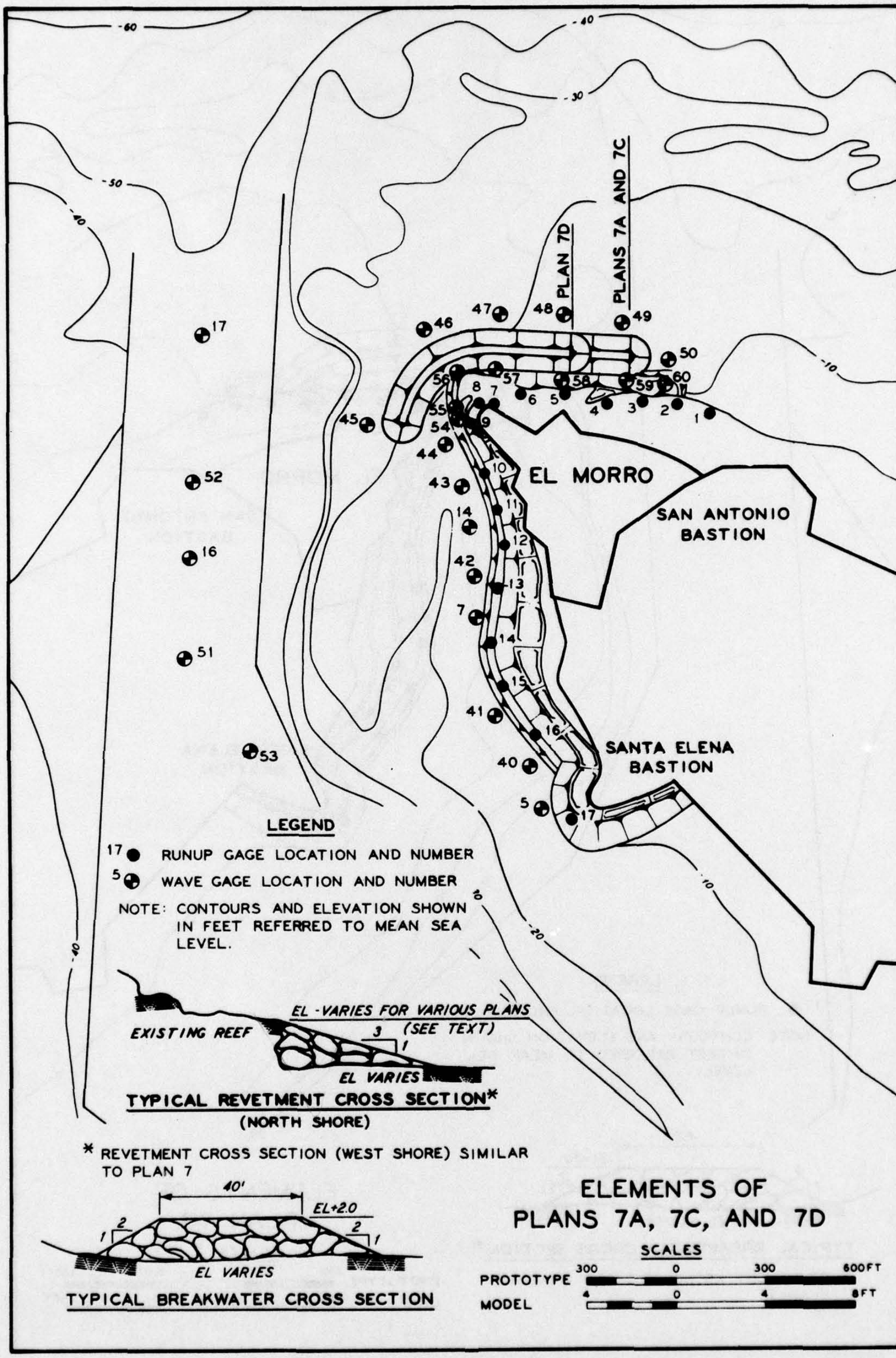
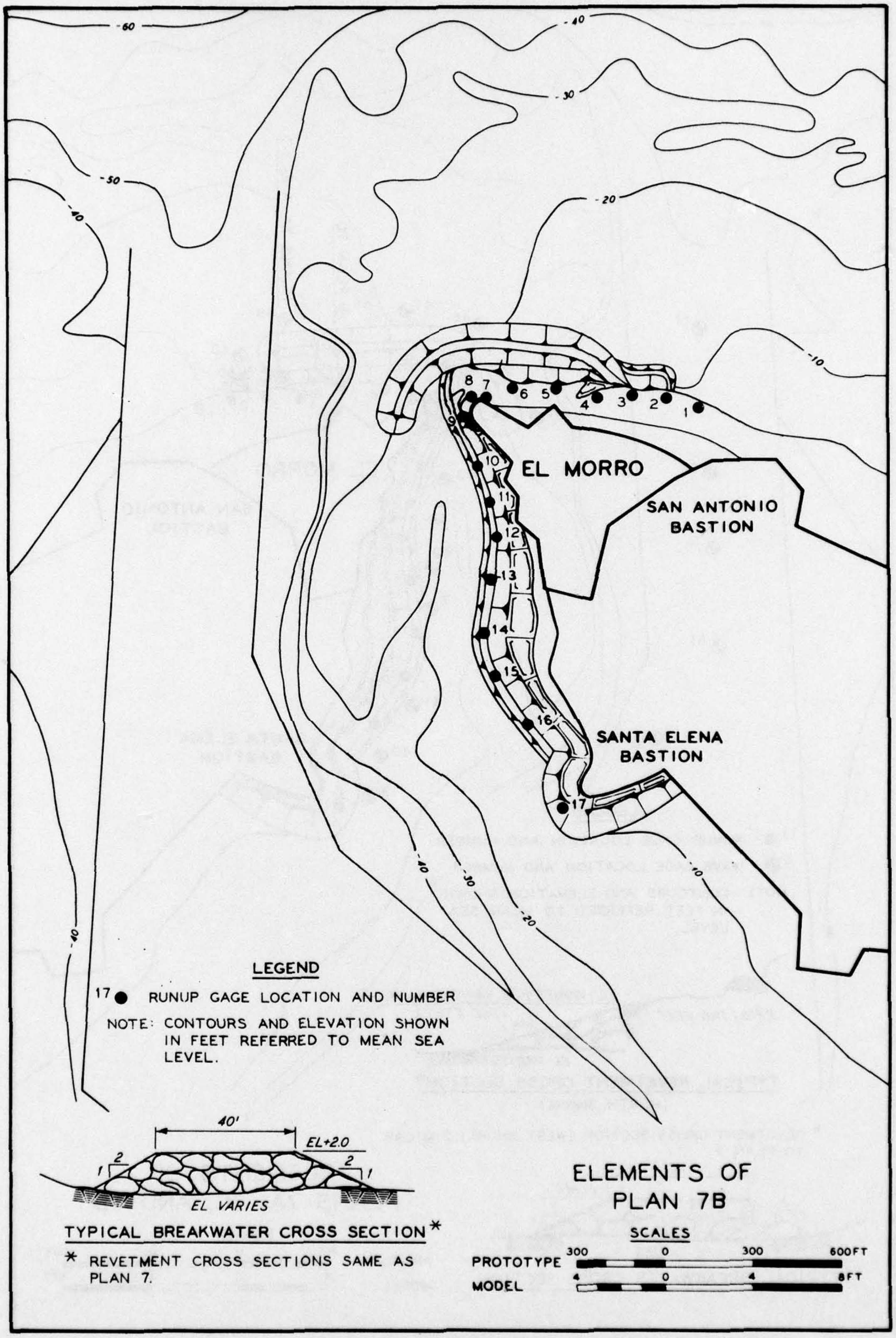
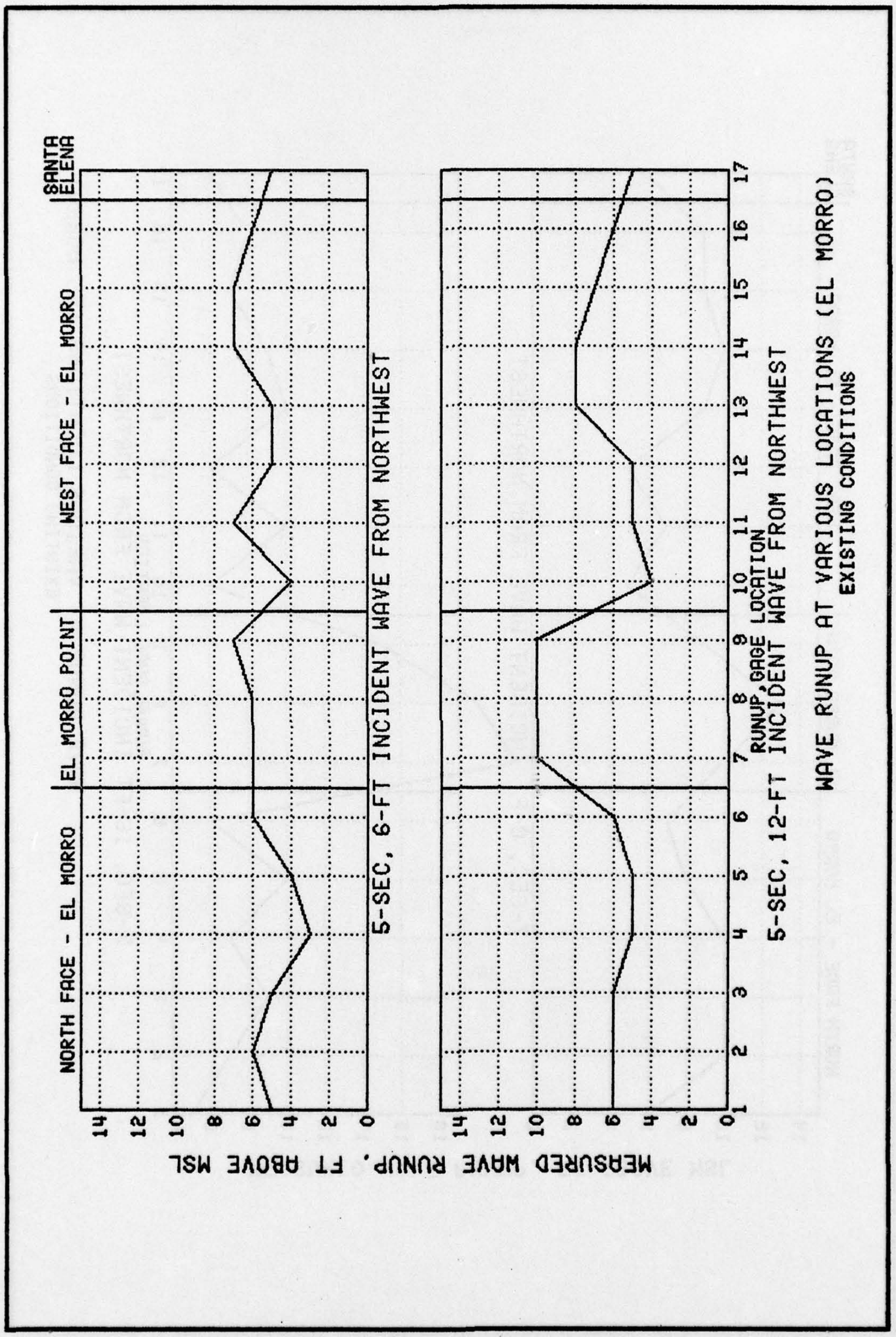

-60
-40
-30
-20
-10
-50
-40
8
7
6
5
4
3
2
1
9
10
11
12
13
14
15
16
17
EL MORRO
SAN ANTONIO
BASTION
SANTA ELENA
BASTION
LEGEND
17 ● RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN IN FEET REFERRED TO MEAN SEA LEVEL.
-40
-30
-20
-10
-40
15'
EL +15.0 *
3
1
20'
EL -7.0 †
1.5
1
EXISTING REEF
EL VARIES
TYPICAL REVETMENT CROSS SECTION
(WEST SHORE)
* ELEVATION VARIES FROM +6.0 TO +15.0 FT
† ELEVATION -12.0 AROUND POINT
EL - TOP OF LEDGE
3
1
EXISTING REEF
EL VARIES
TYPICAL REVETMENT CROSS SECTION *
(NORTH SHORE)
ELEMENTS OF
PLAN 7
SCALES
300 0 300 600 FT
PROTOTYPE
4 0 4 8 FT
MODEL

PLATE 10

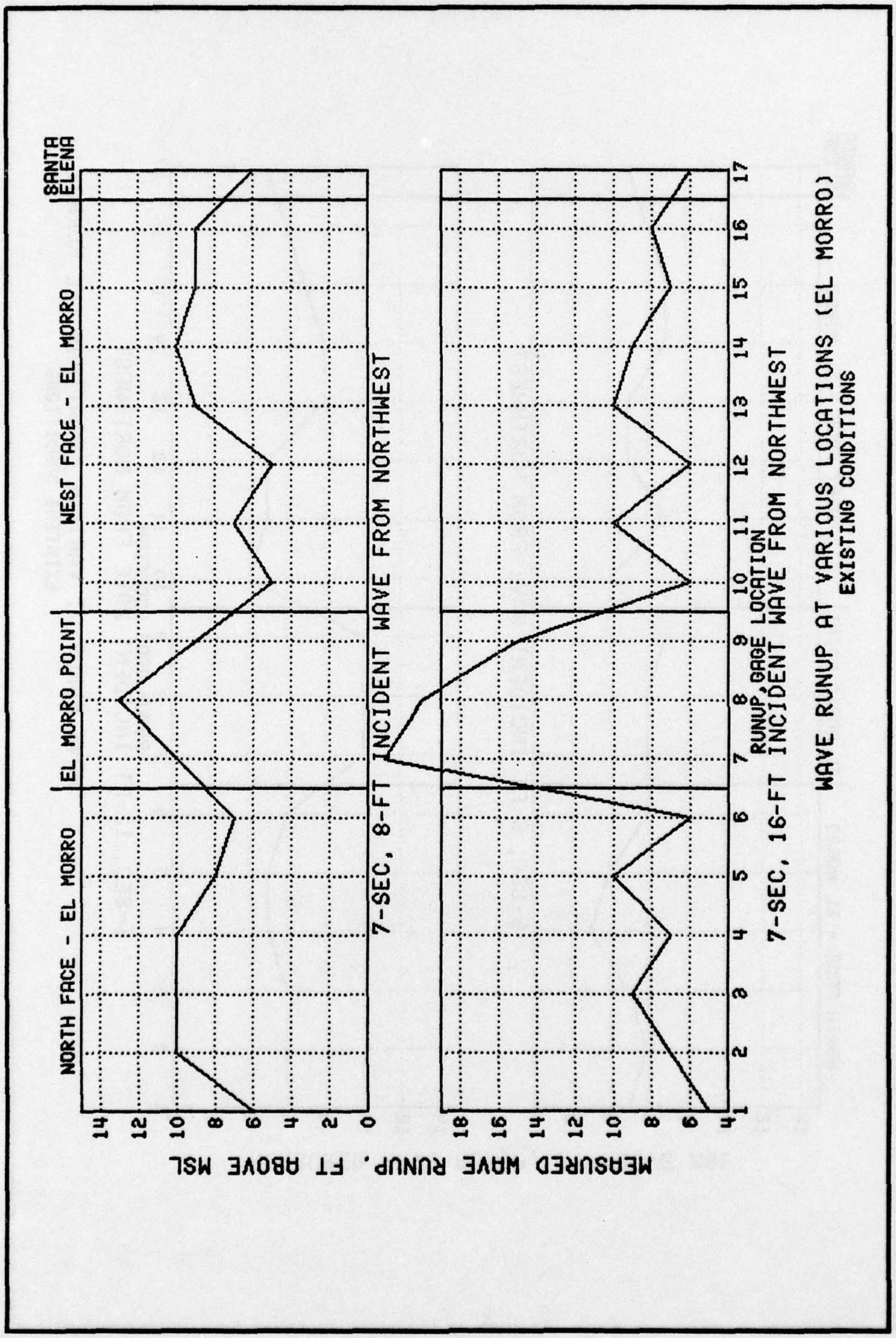


ELEMENTS OF PLANS 7A, 7C, AND 7D

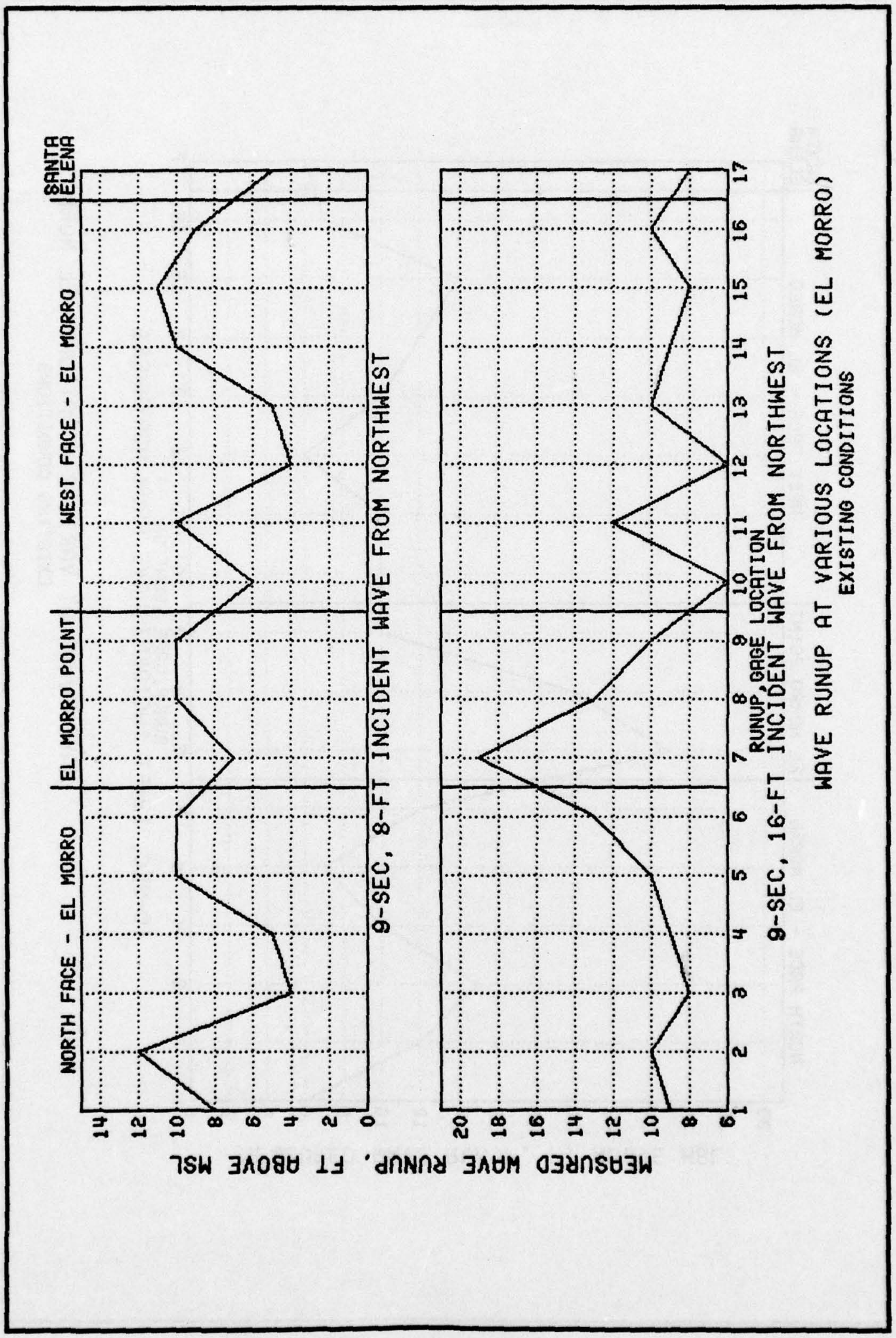

-60
-40
-30
-50
-40
-20
-10
8
7
6
5
4
3
2
1
9
10
11
12
13
14
15
16
17
EL MORRO
SAN ANTONIO
BASTION
SANTA ELENA
BASTION
-40
-30
-20
-10
-40
LEGEND
17 ● RUNUP GAGE LOCATION AND NUMBER
NOTE: CONTOURS AND ELEVATION SHOWN
IN FEET REFERRED TO MEAN SEA
LEVEL.
40'
EL+2.0
2
1
2
1
EL VARIES
TYPICAL BREAKWATER CROSS SECTION*
* REVETMENT CROSS SECTIONS SAME AS
PLAN 7.
ELEMENTS OF
PLAN 7B
SCALES
PROTOTYPE 300 0 300 600 FT
MODEL 4 0 4 8 FT



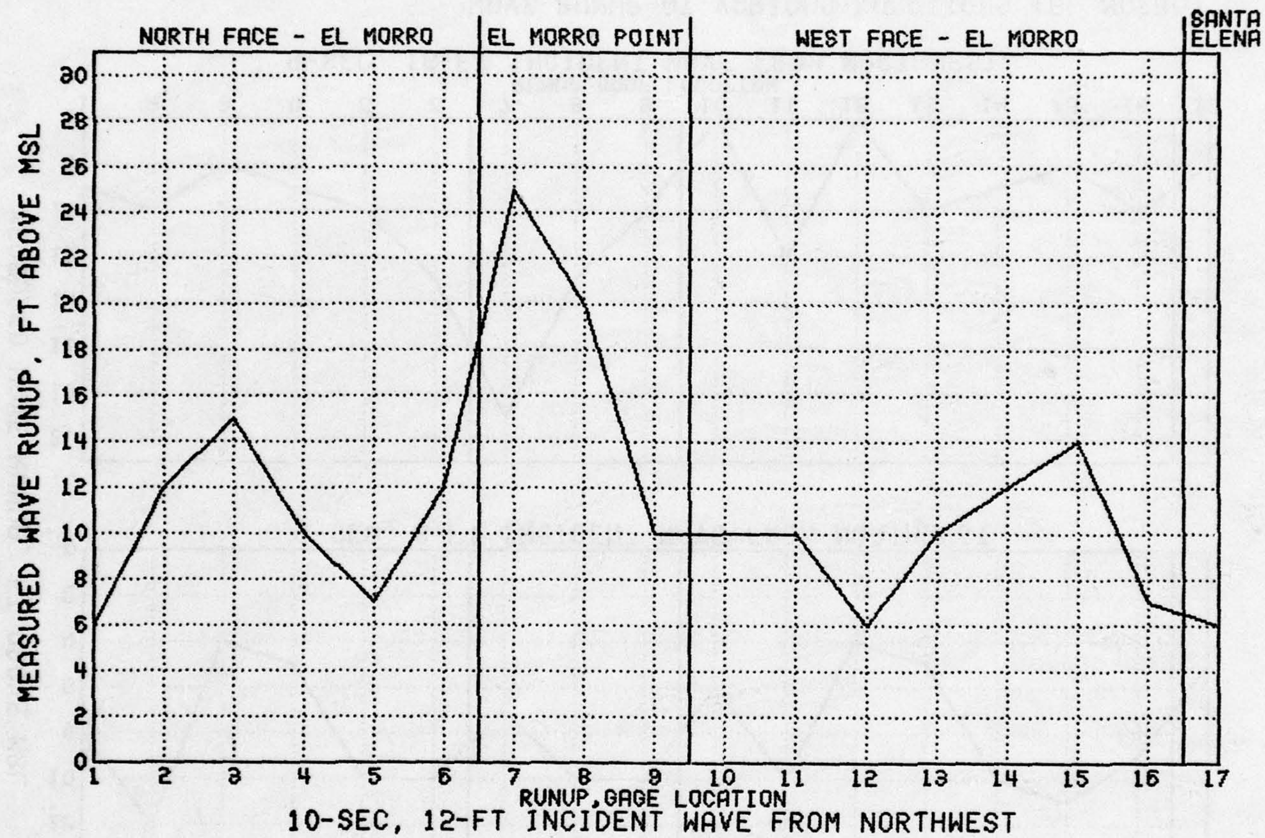
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



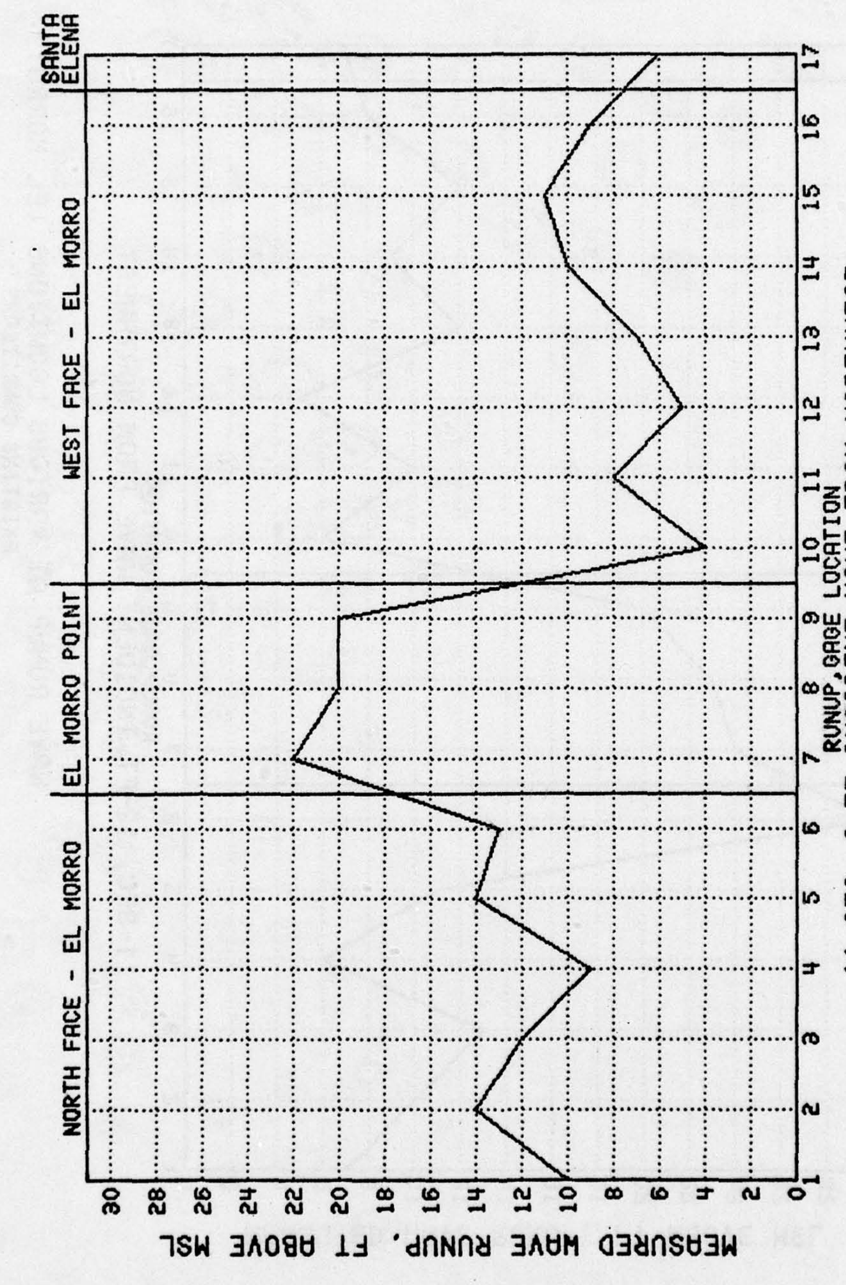
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



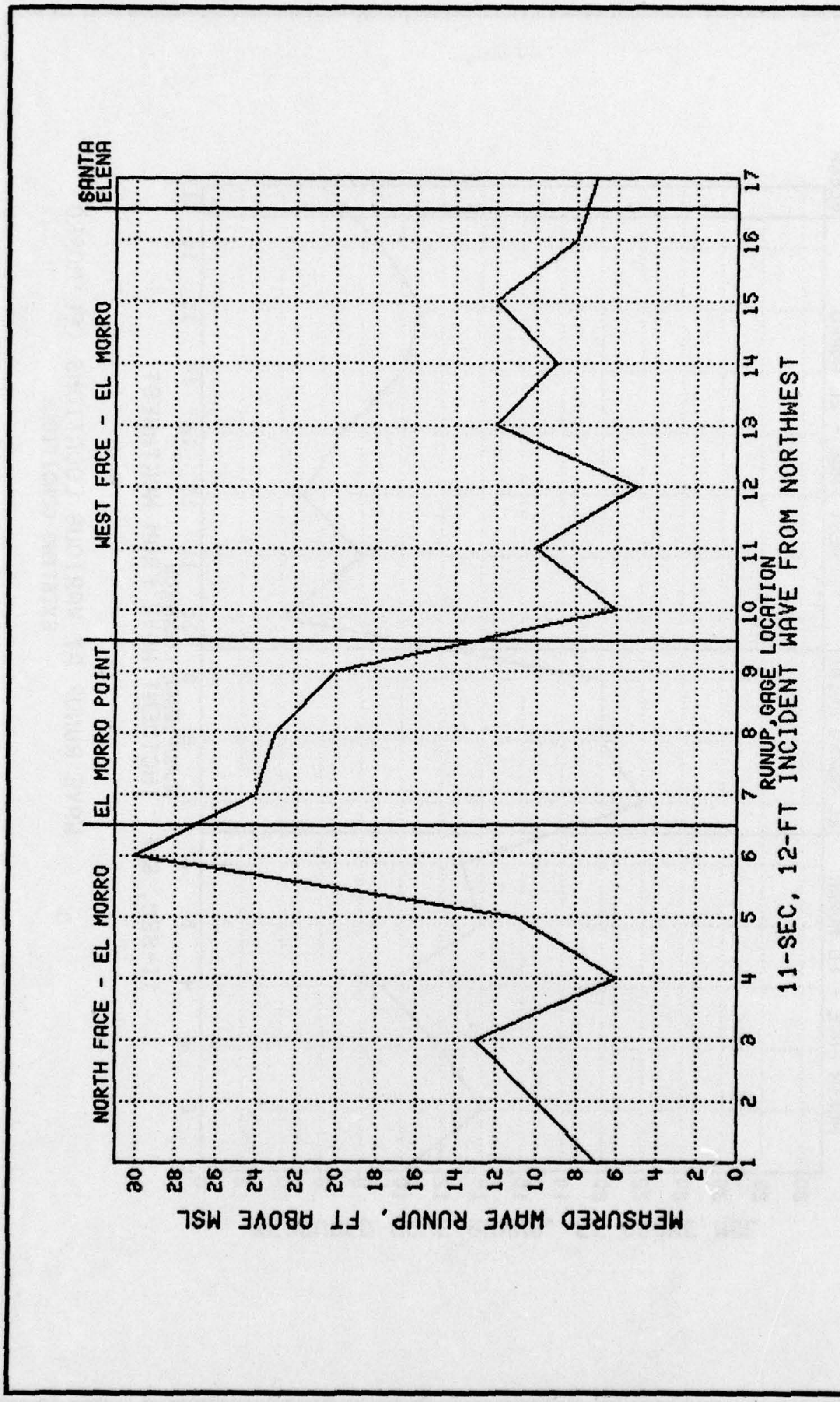
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



11-SEC, 6-FT INCIDENT WAVE FROM NORTHWEST

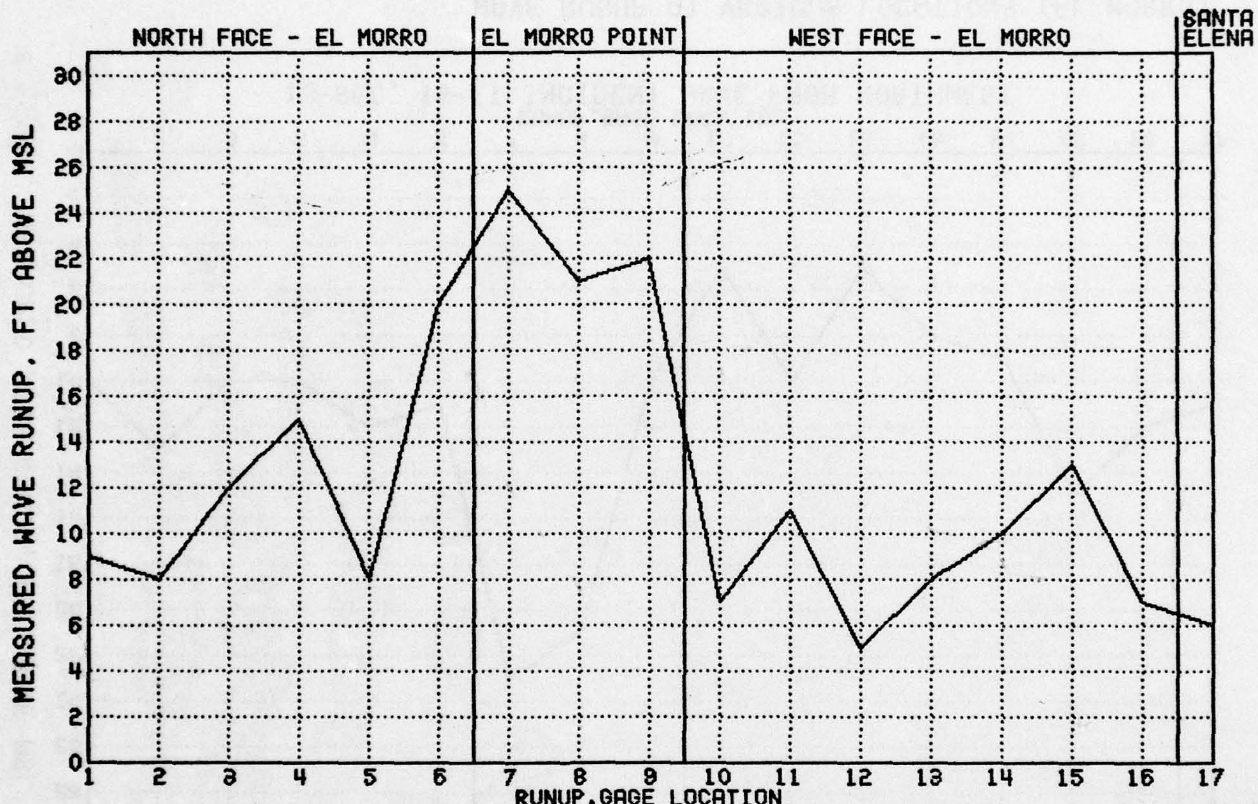
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

EXISTING CONDITIONS



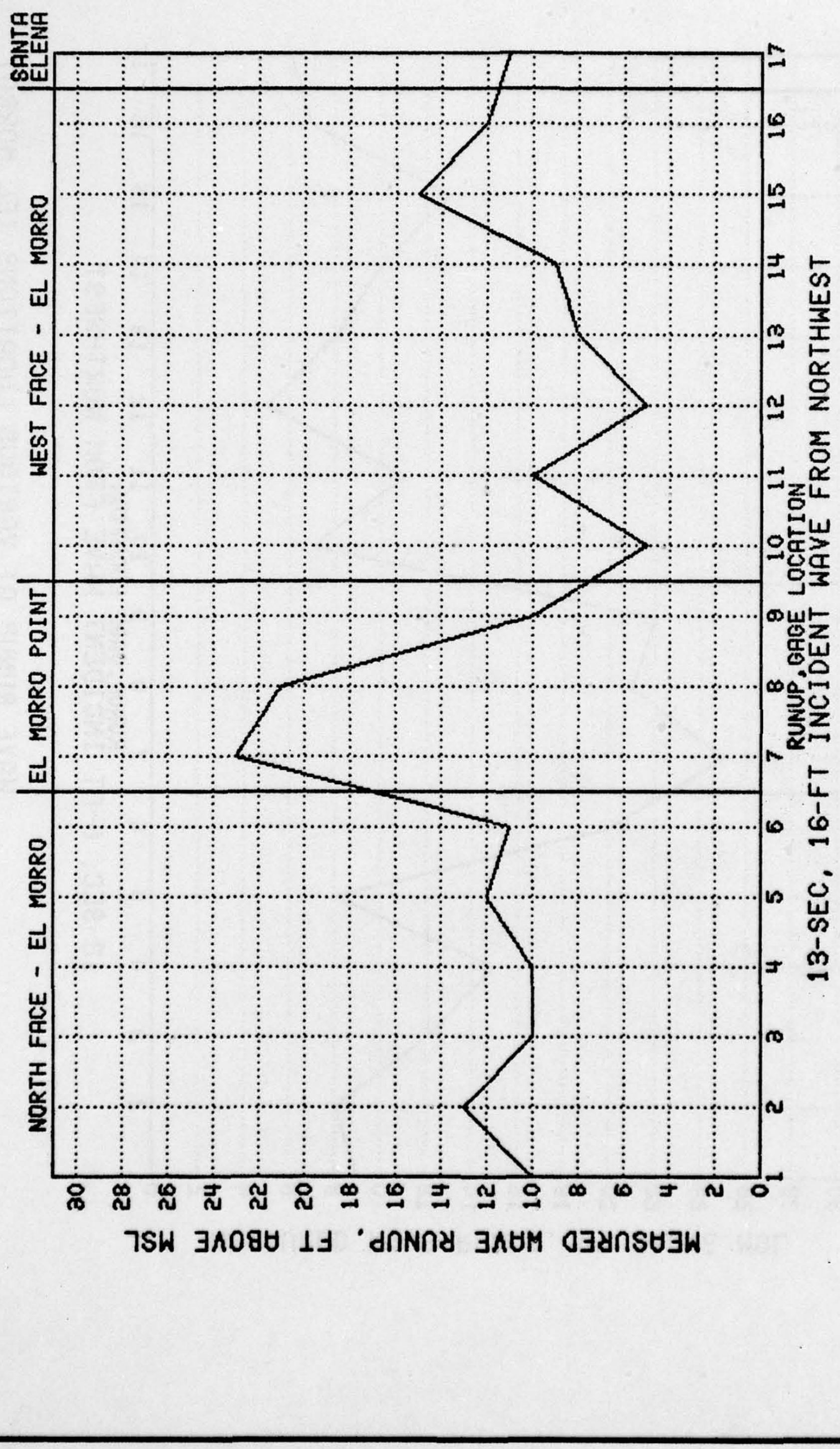
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

PLATE 18

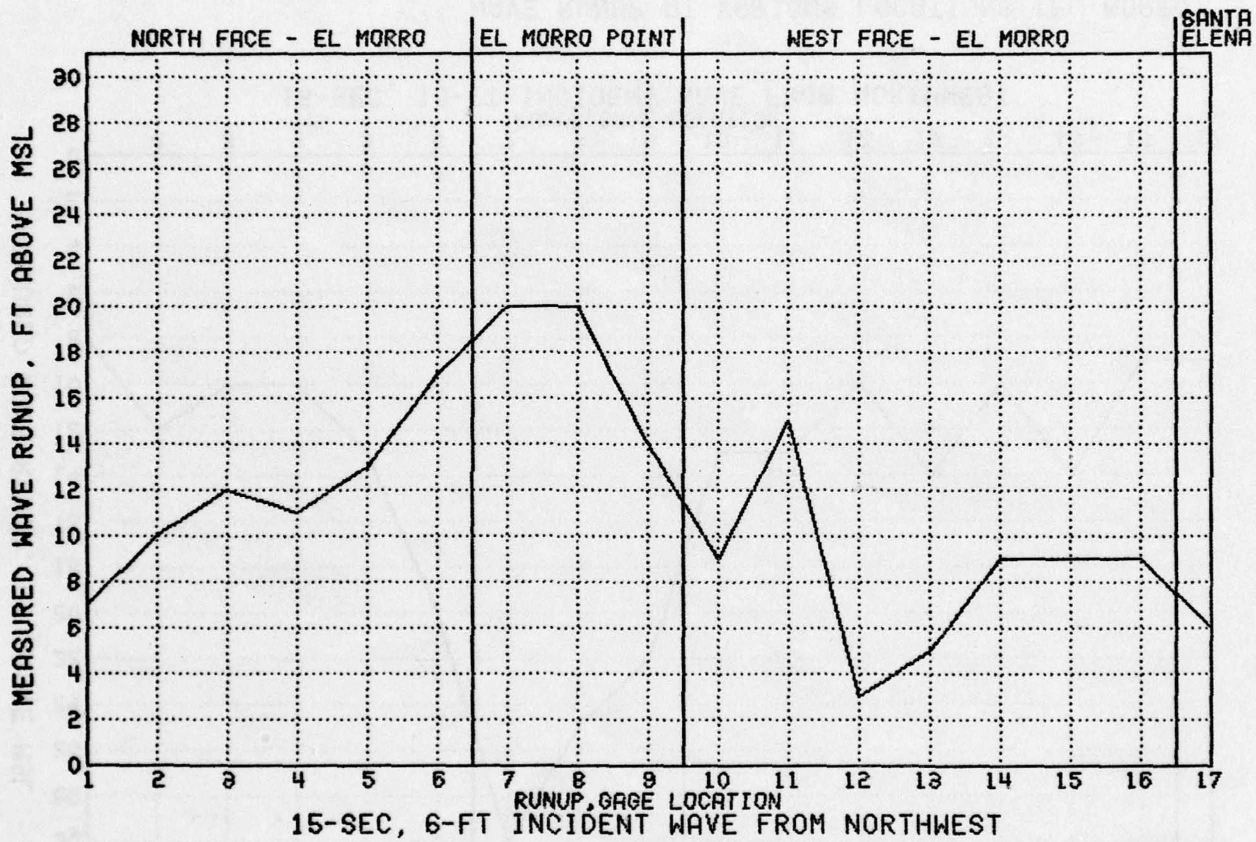


13-SEC, 8-FT INCIDENT WAVE FROM NORTHWEST

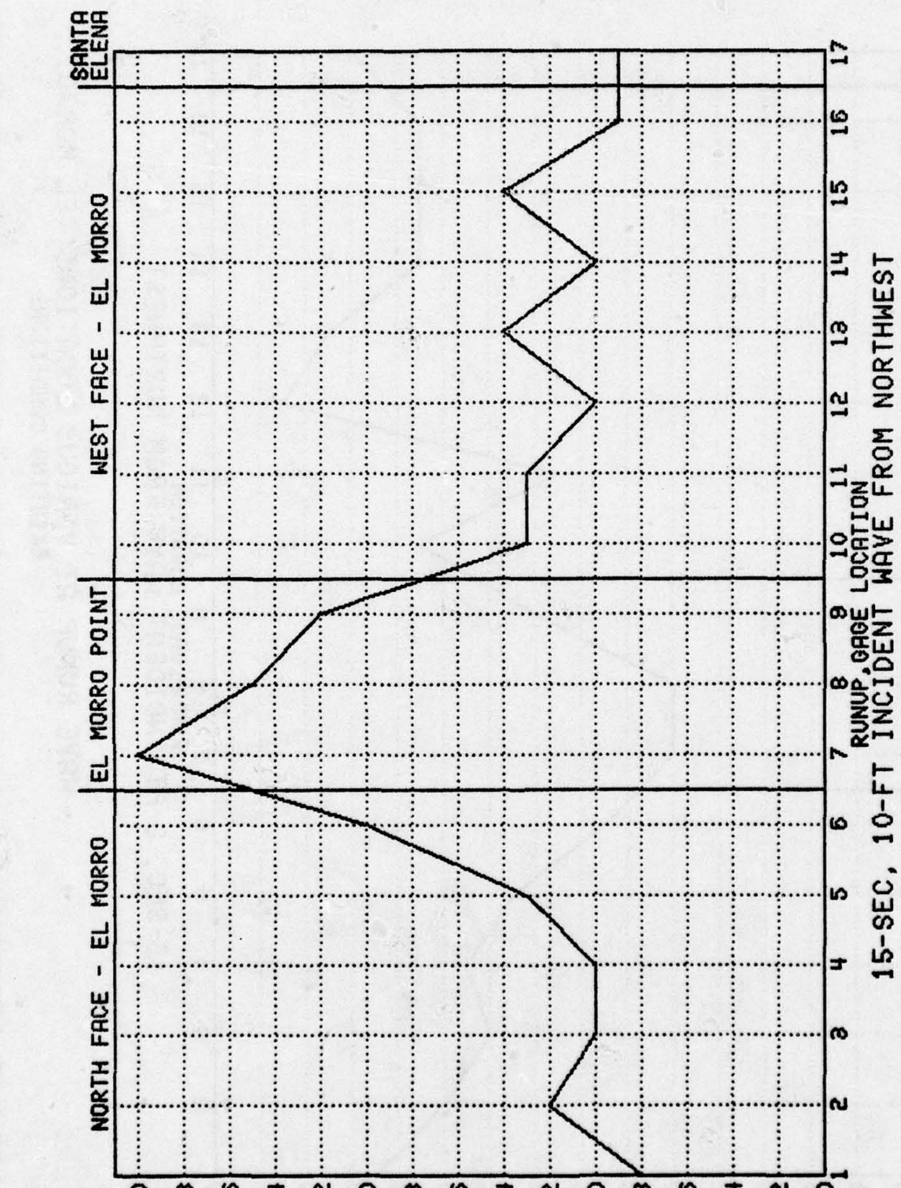
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

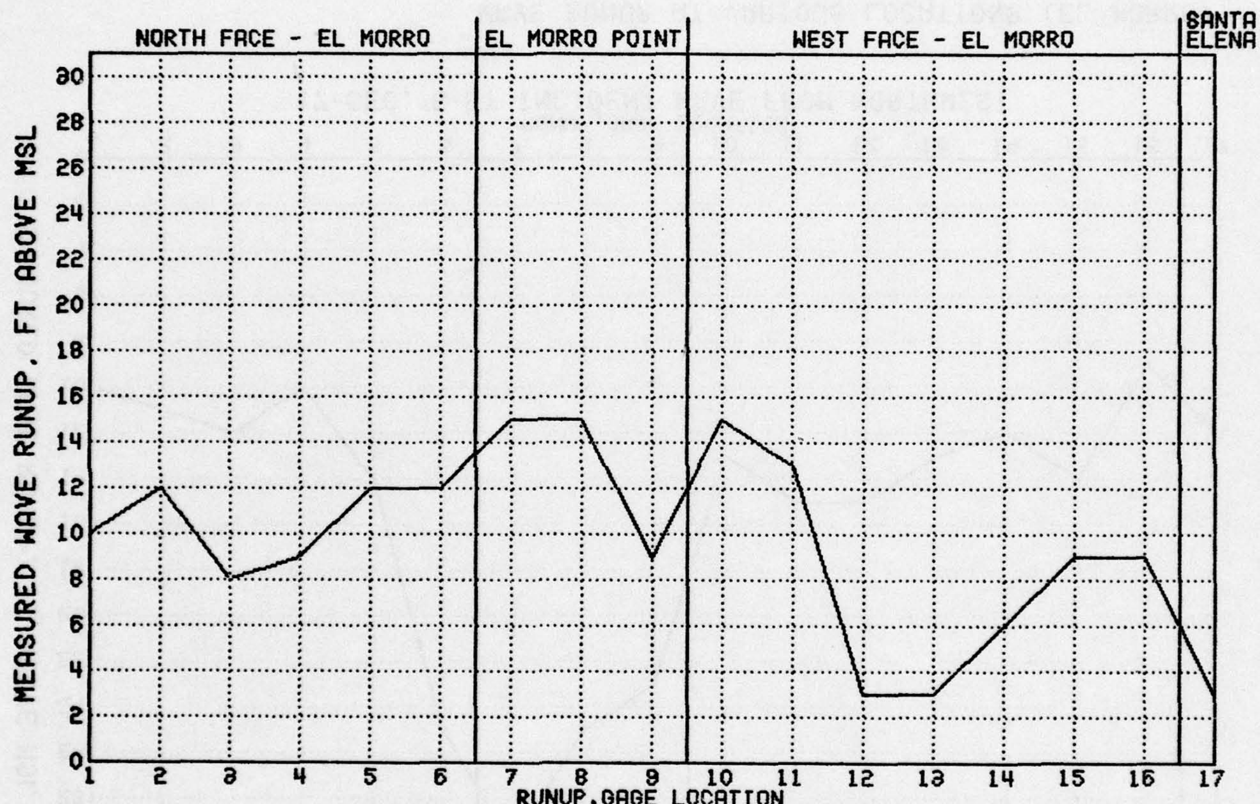


15-SEC, 10-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

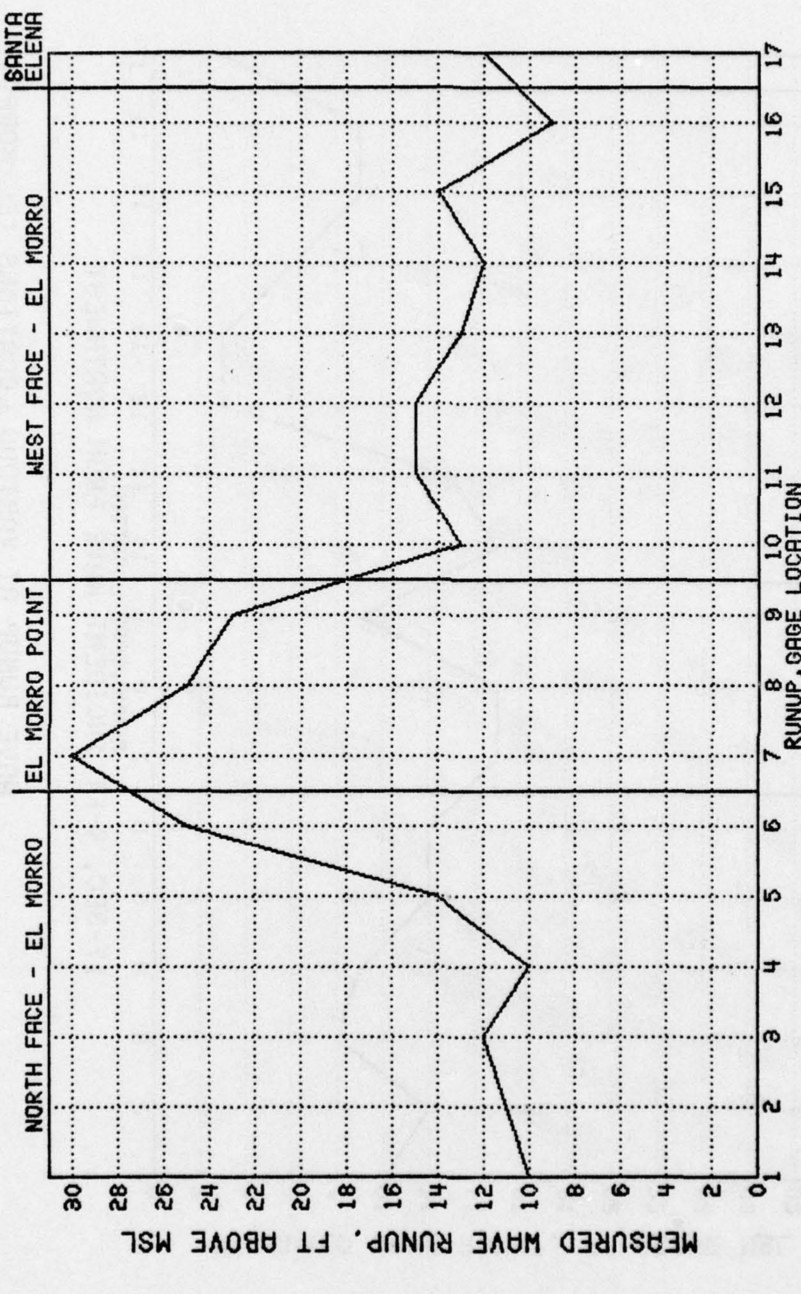
EXISTING CONDITIONS

PLATE 22



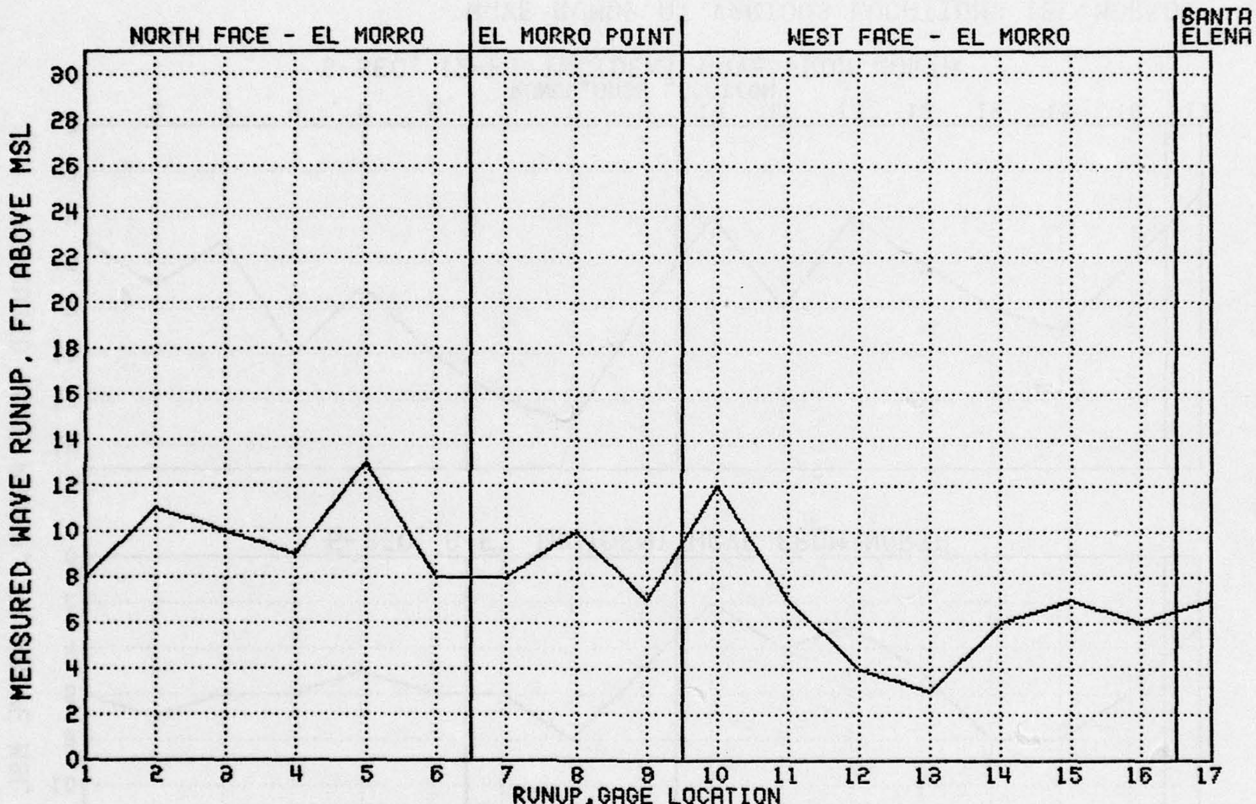
17-SEC, 4-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



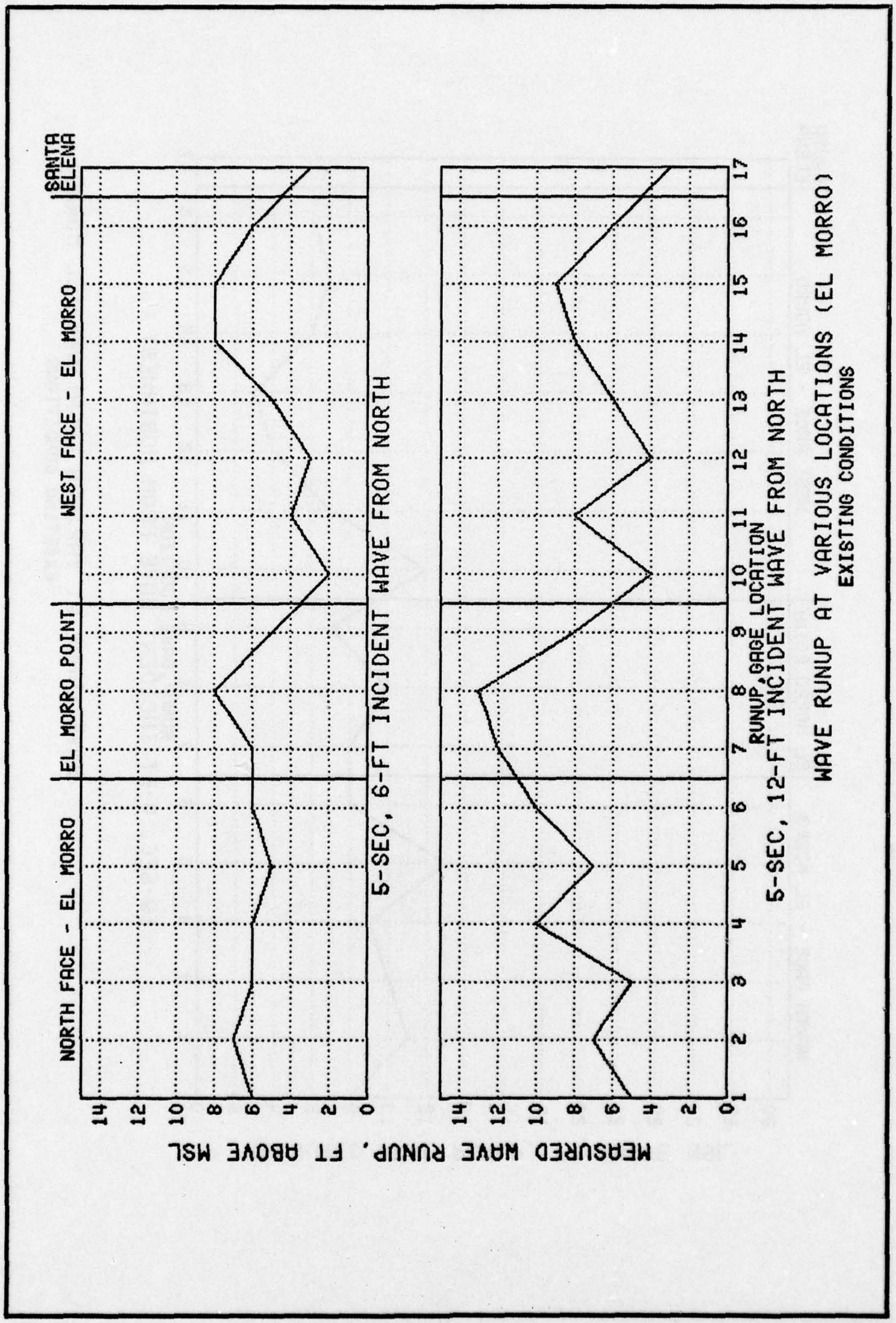
17-SEC, 8-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

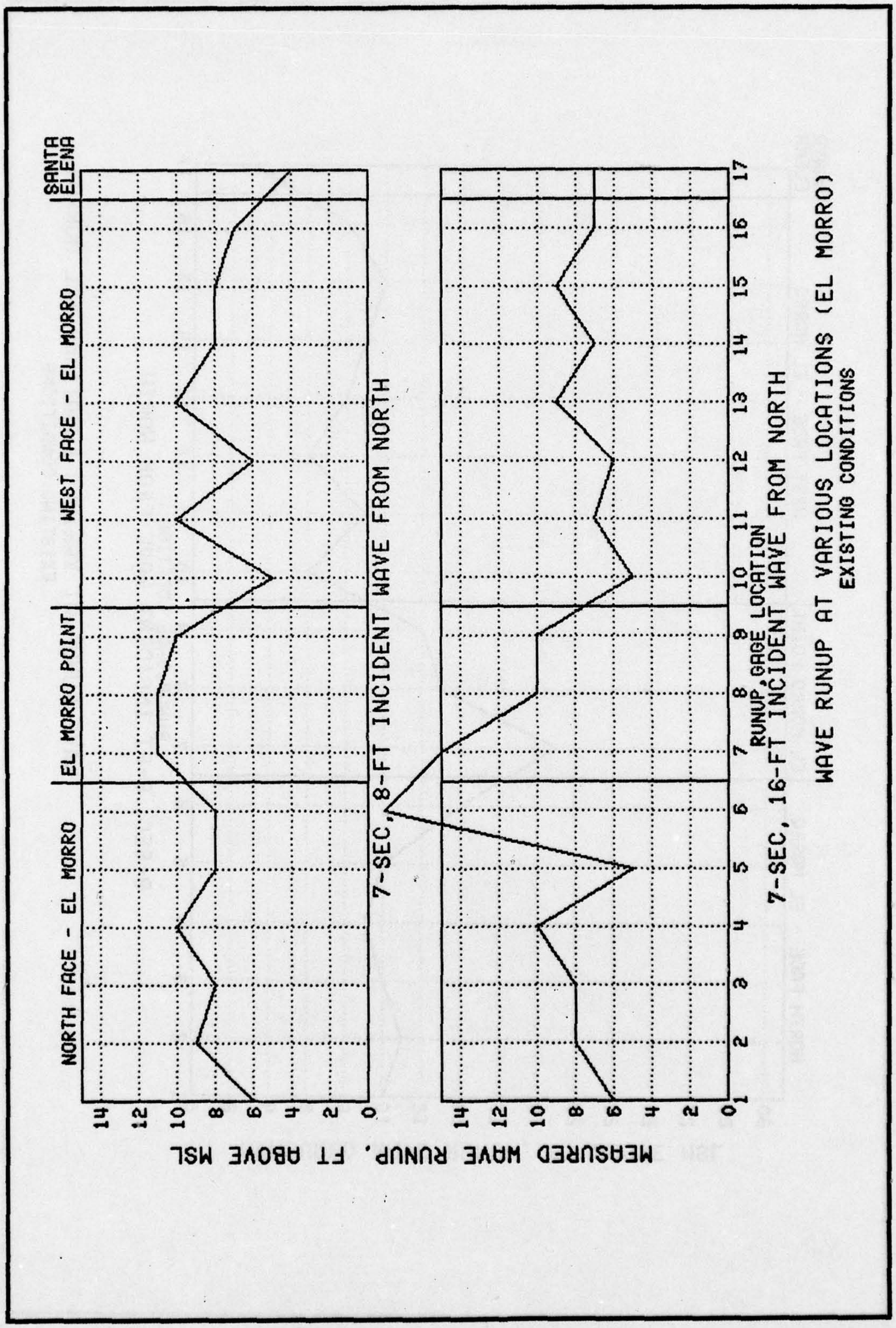


19-SEC, 4-FT INCIDENT WAVE FROM NORTHWEST

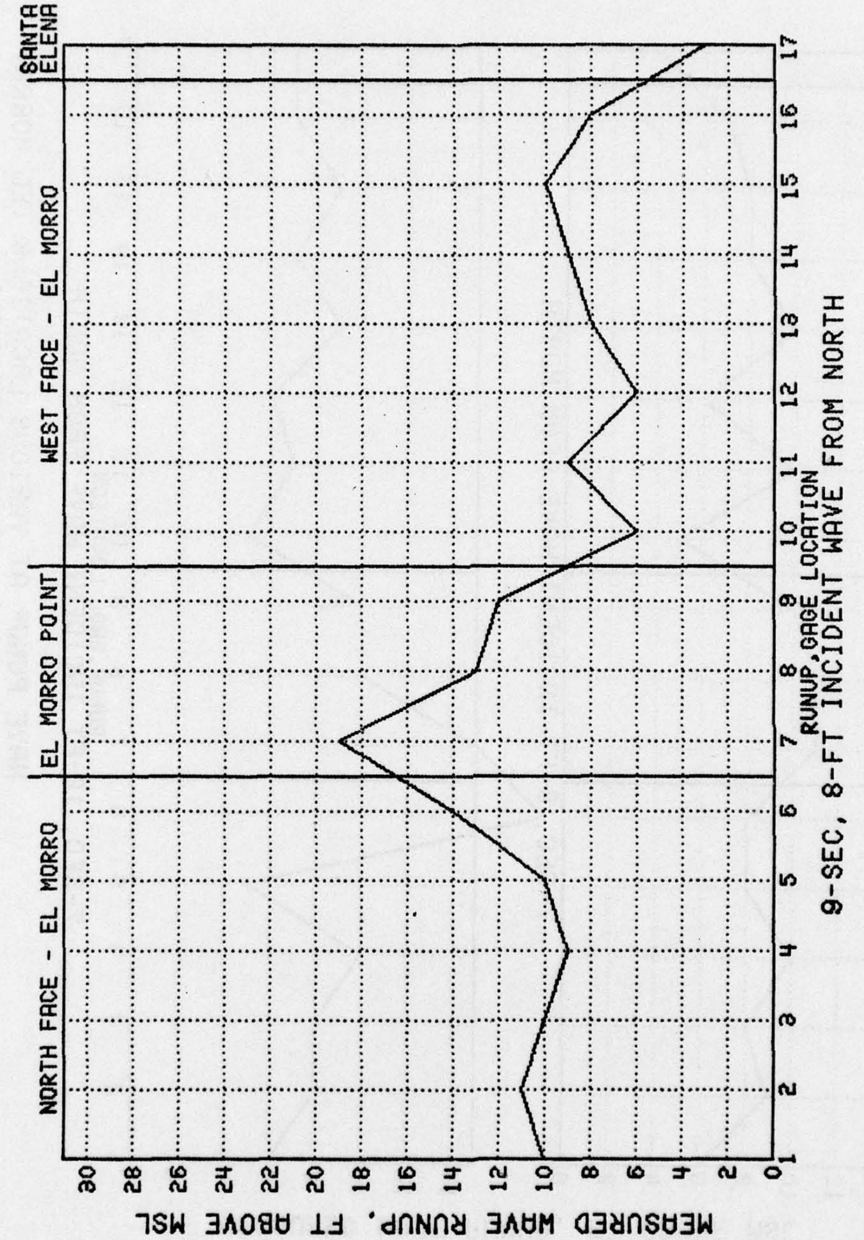
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



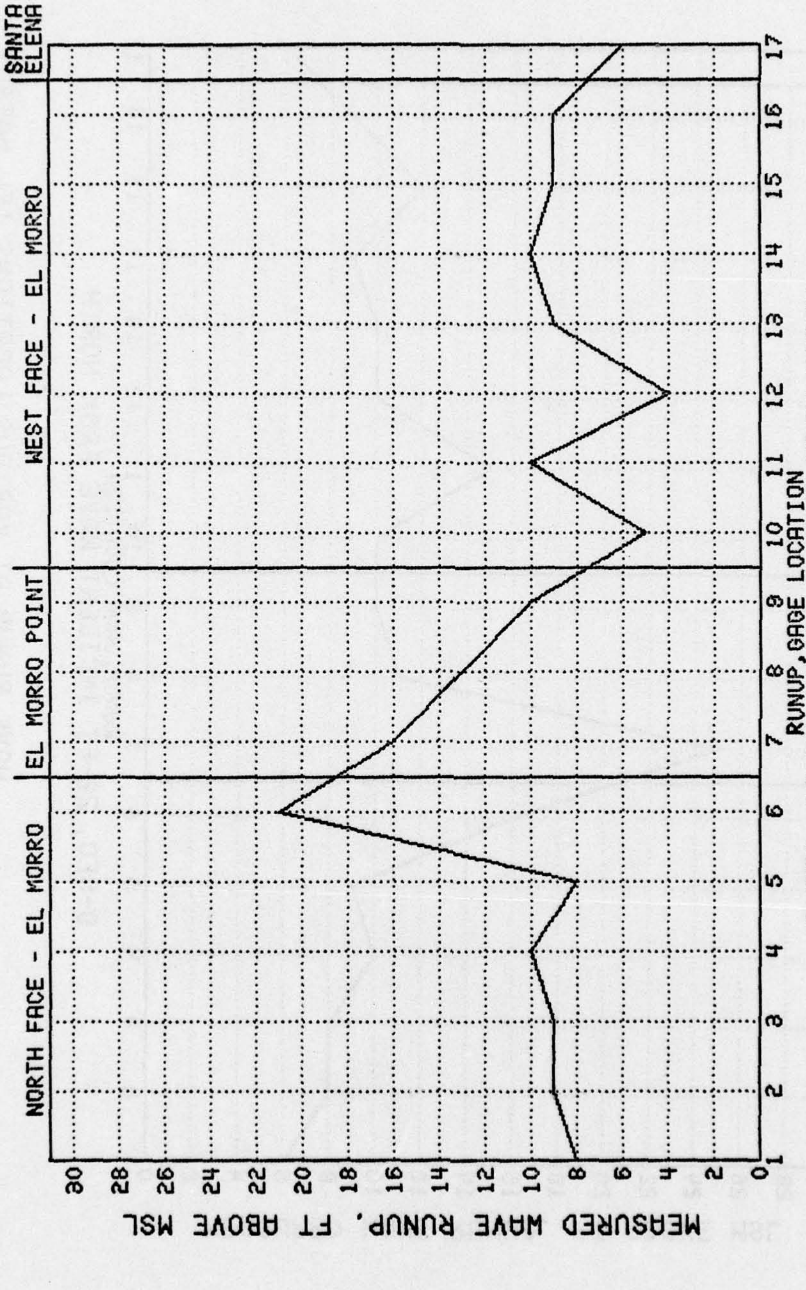
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



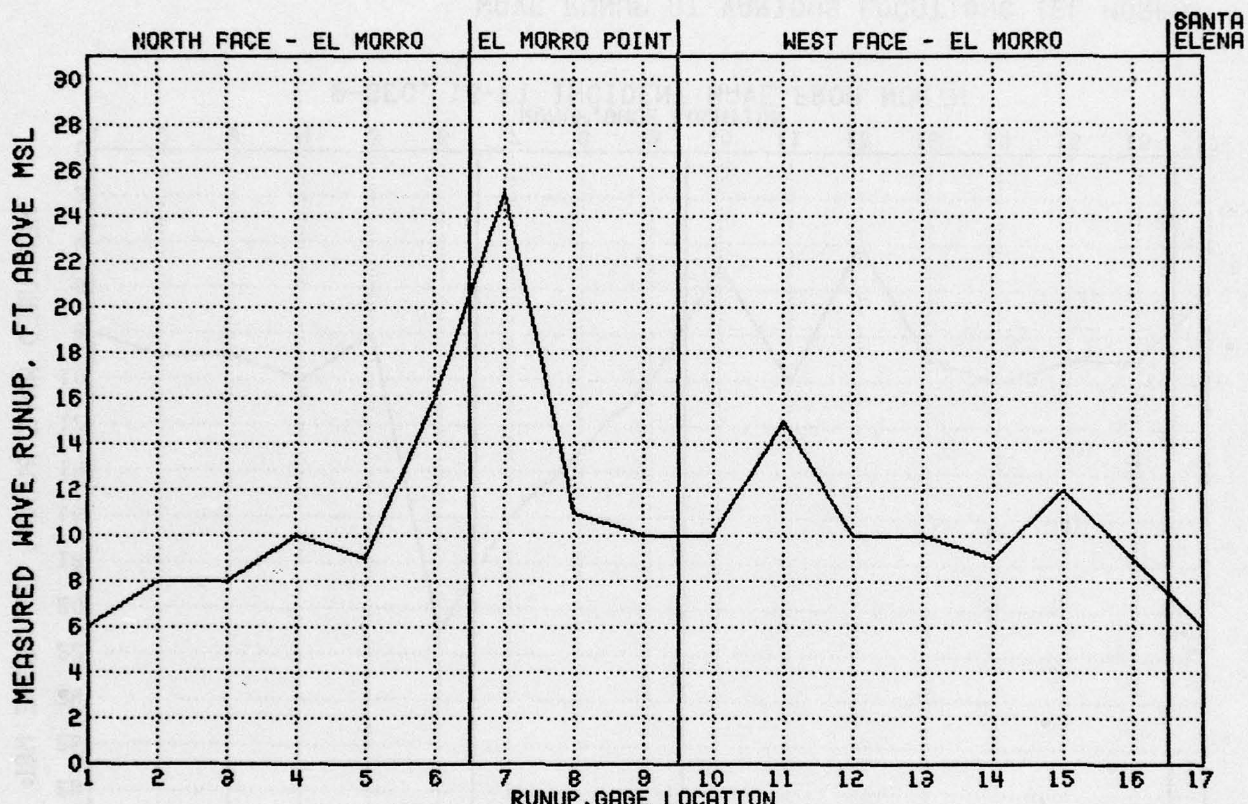
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



9-SEC, 16-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

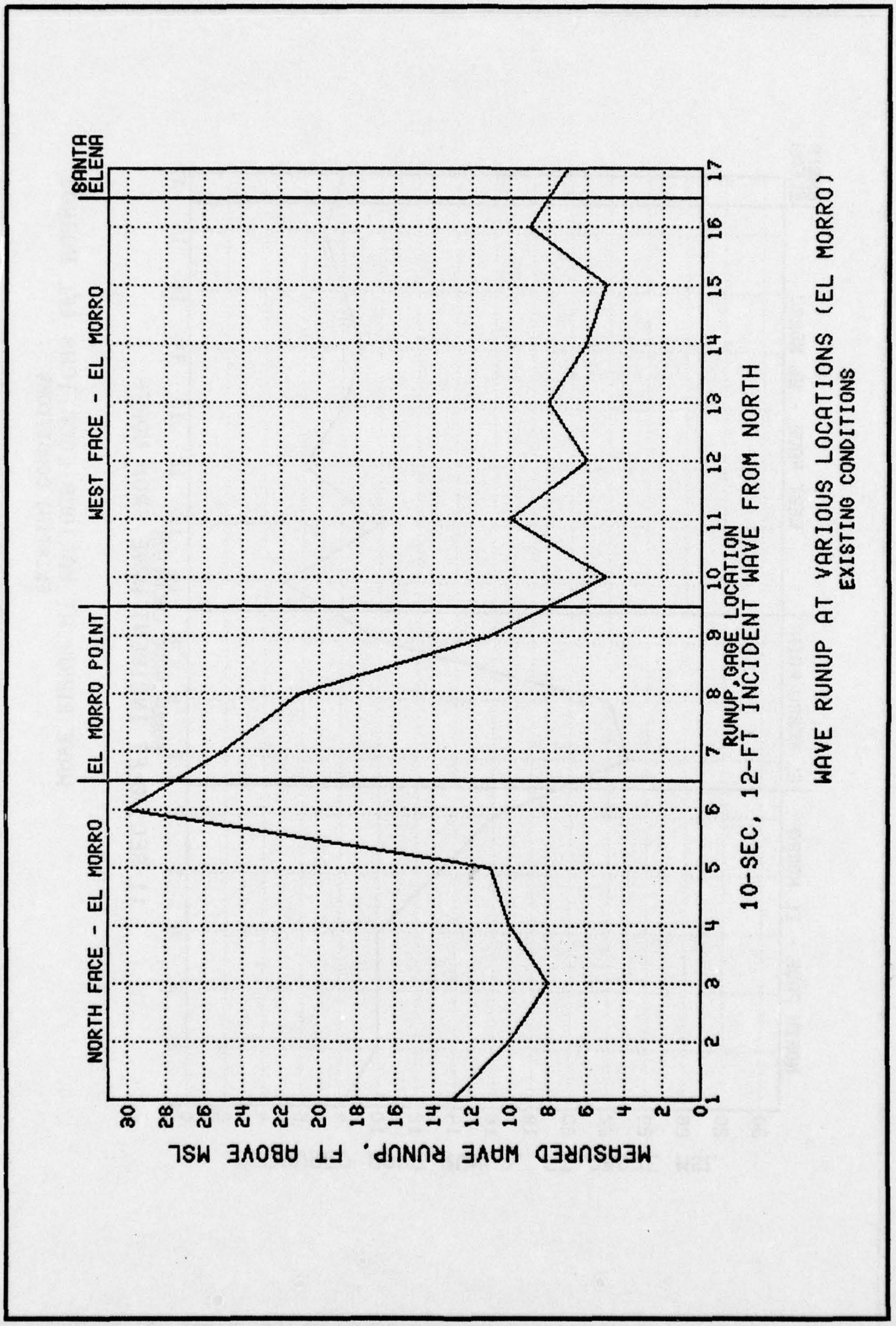
EXISTING CONDITIONS



9-SEC, 22-FT INCIDENT WAVE FROM NORTH

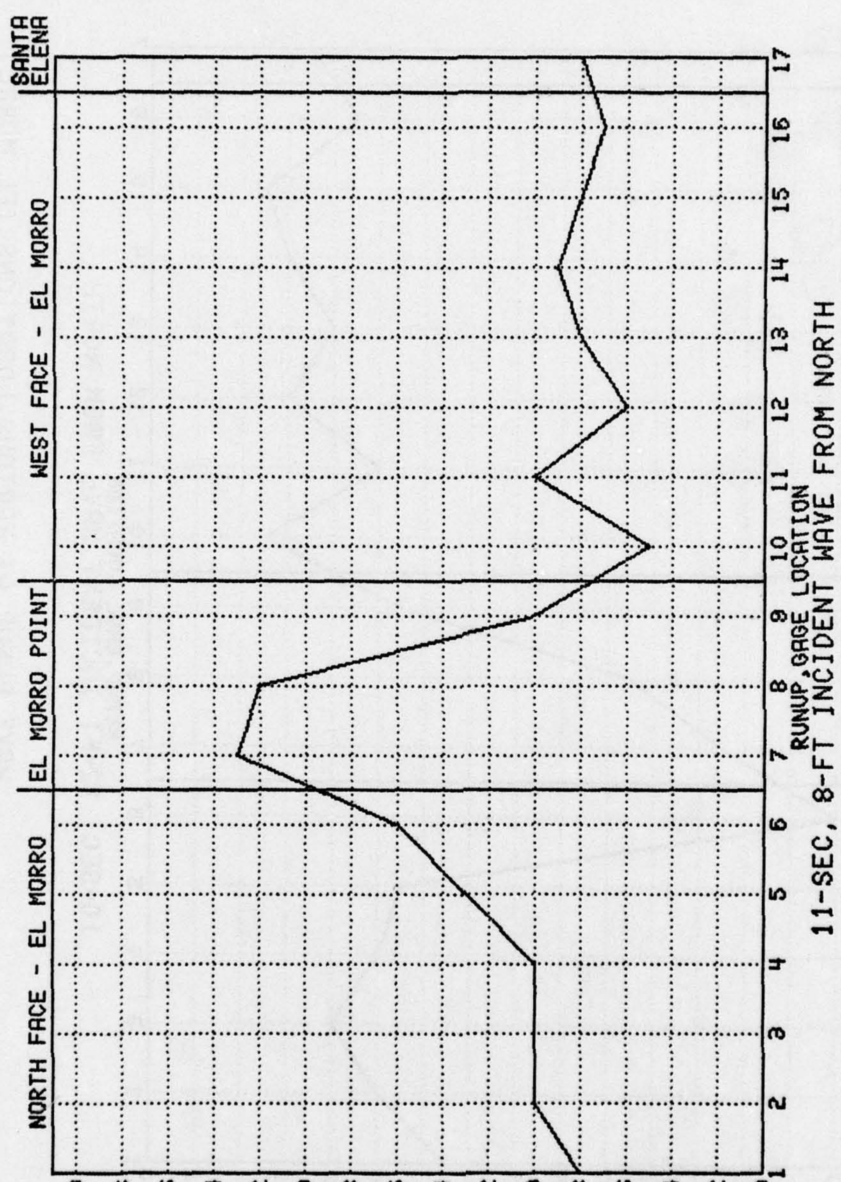
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

EXISTING CONDITIONS



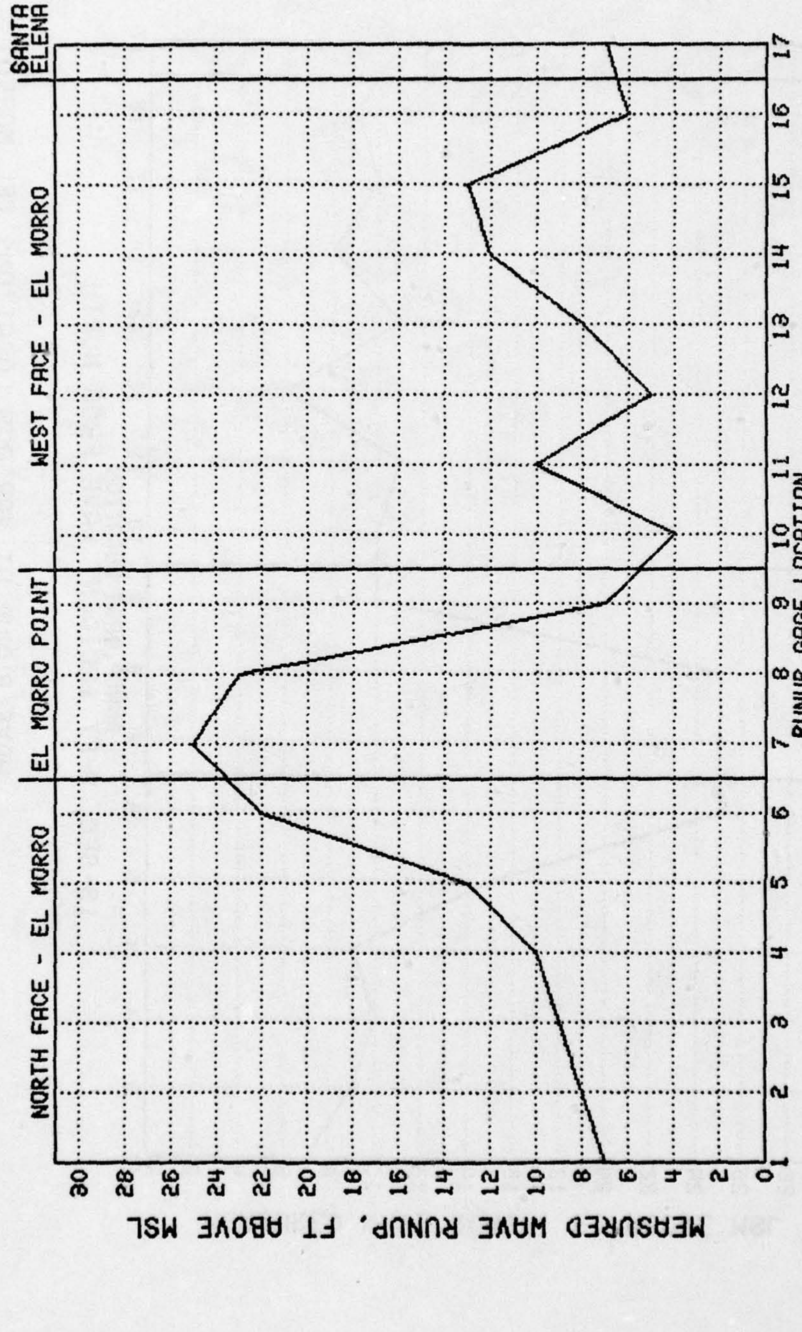
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

PLATE 31



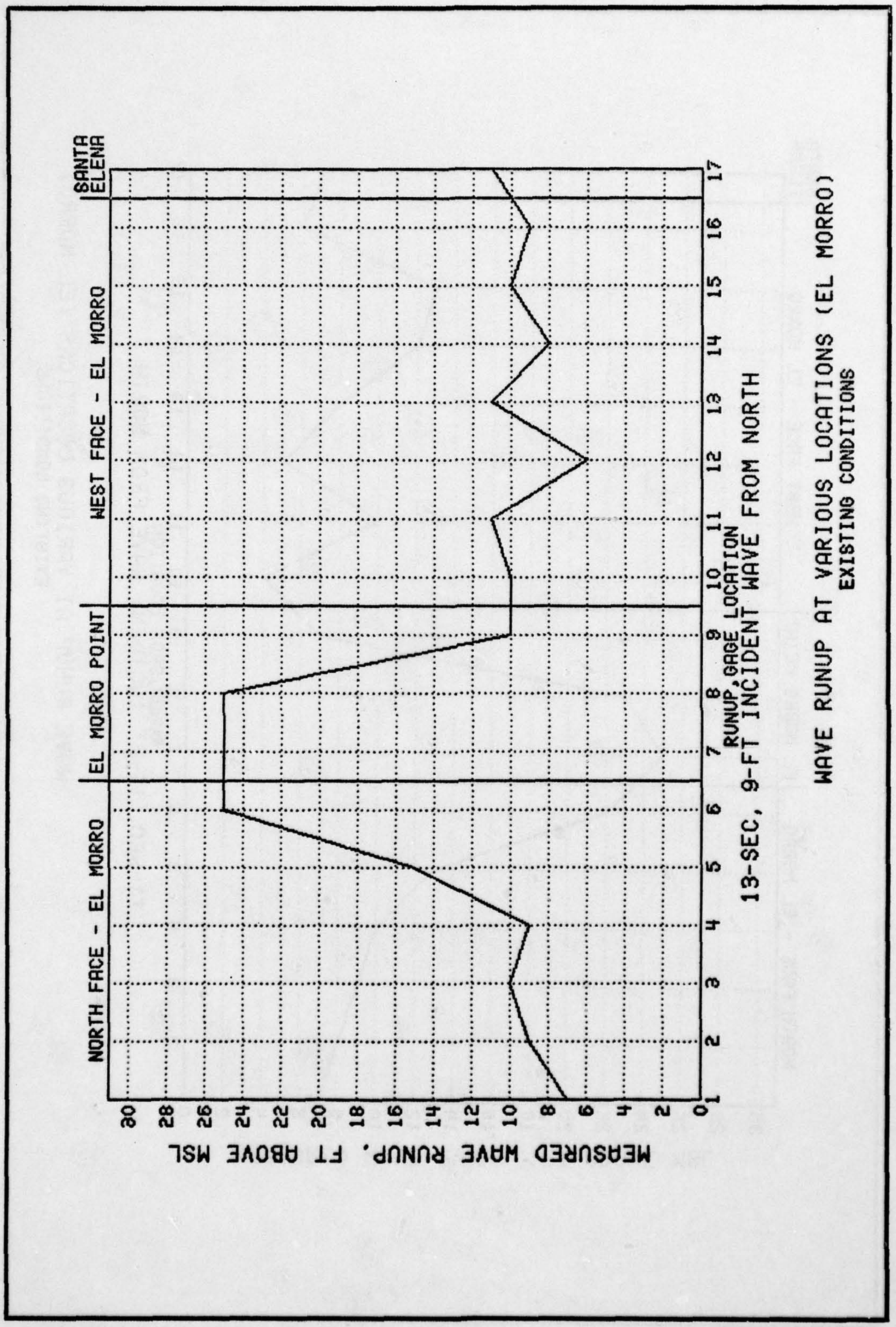
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

EXISTING CONDITIONS



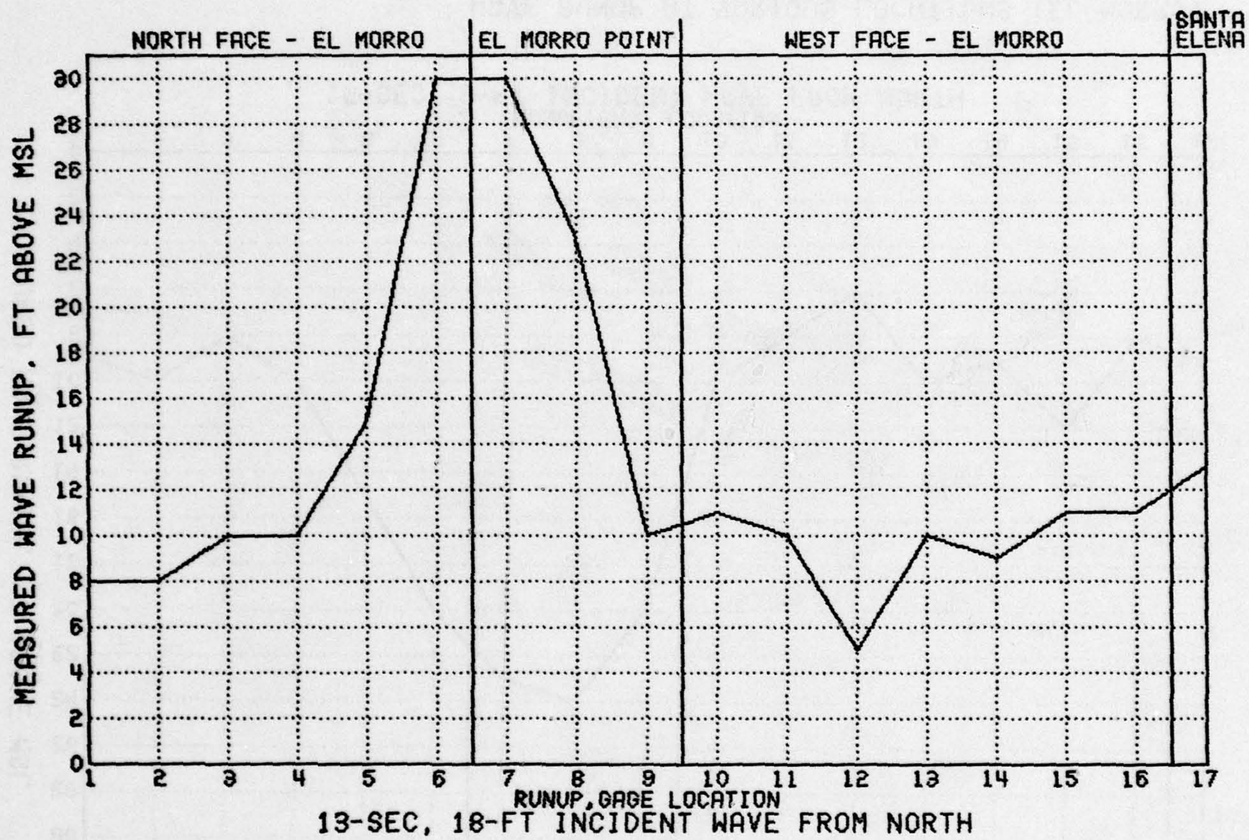
11-SEC, 16-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

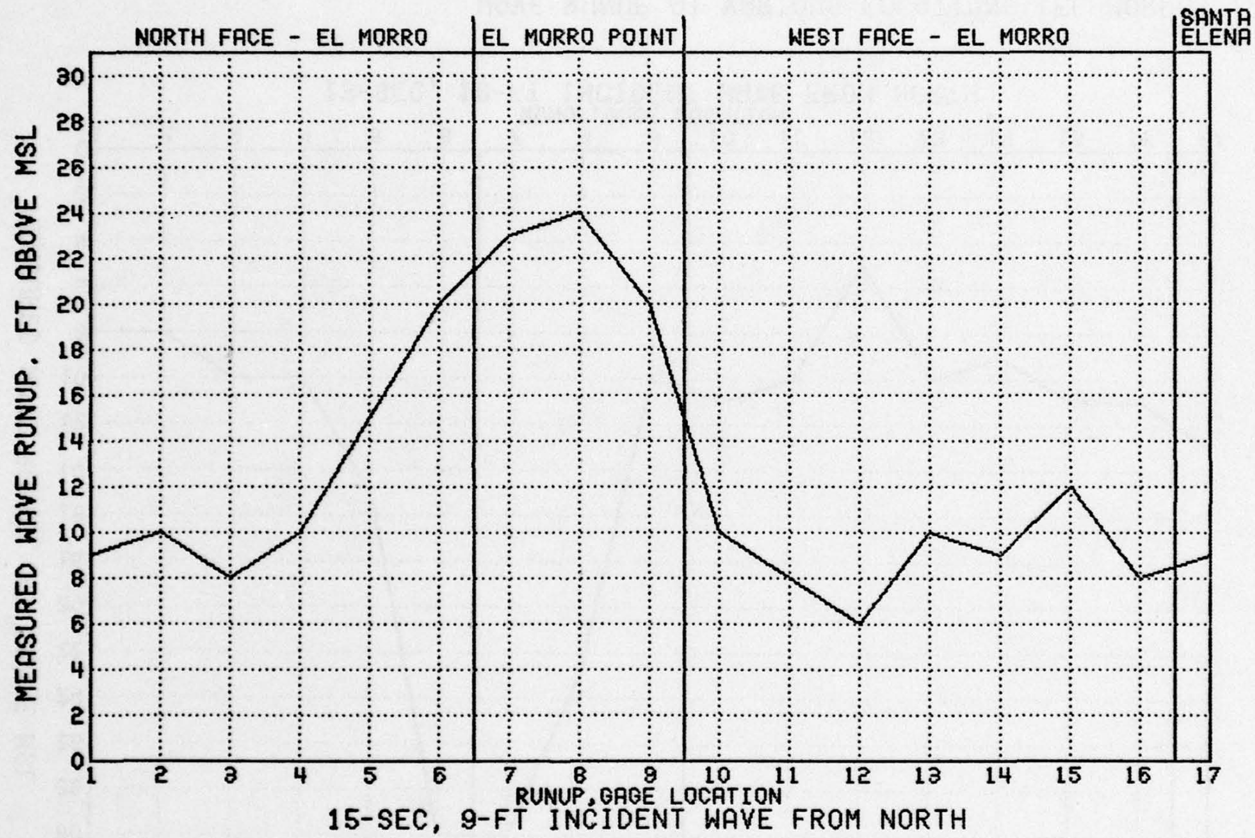


MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
RUNUP,GAGE LOCATION
13-SEC, 9-FT INCIDENT WAVE FROM NORTH
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

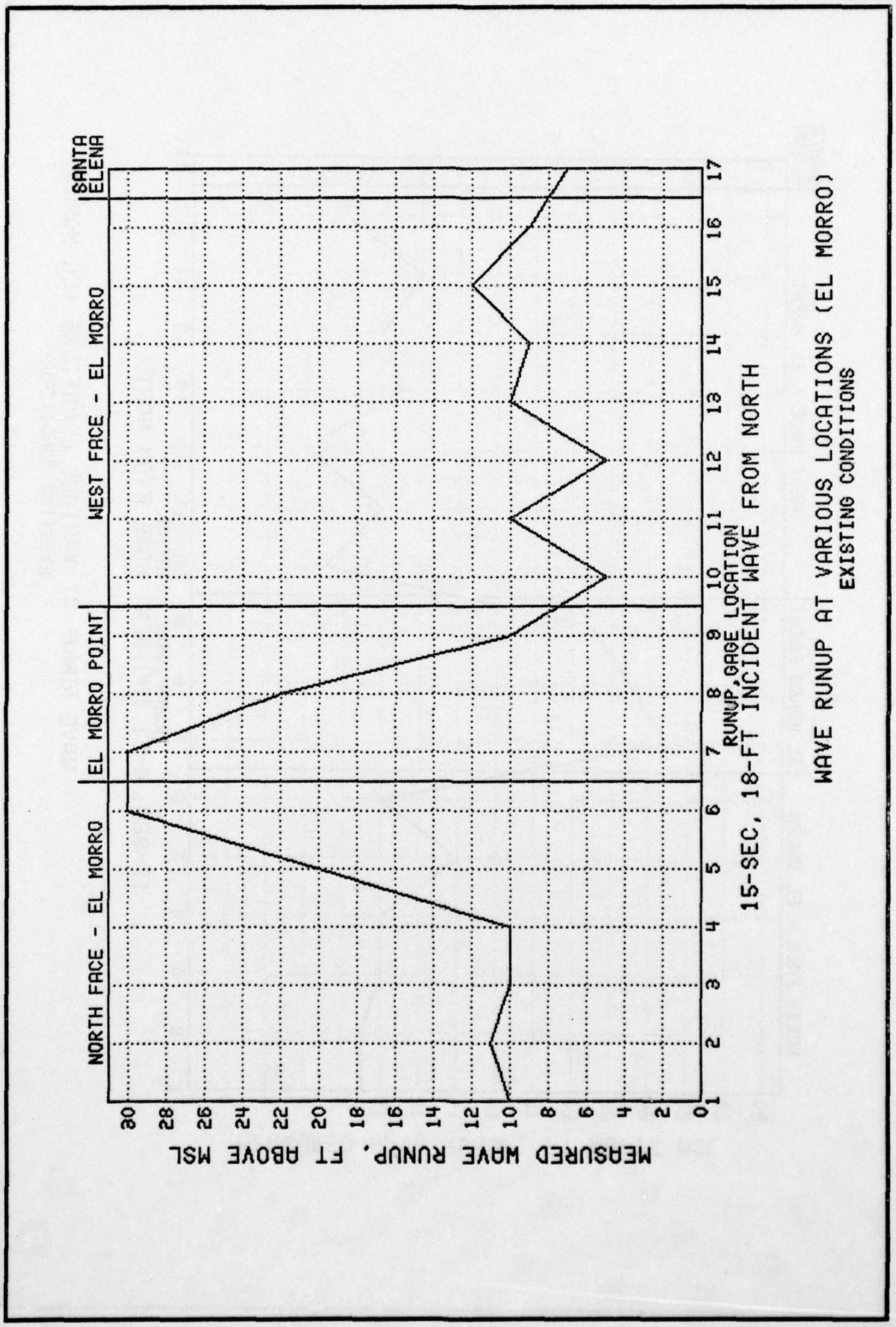
PLATE 34



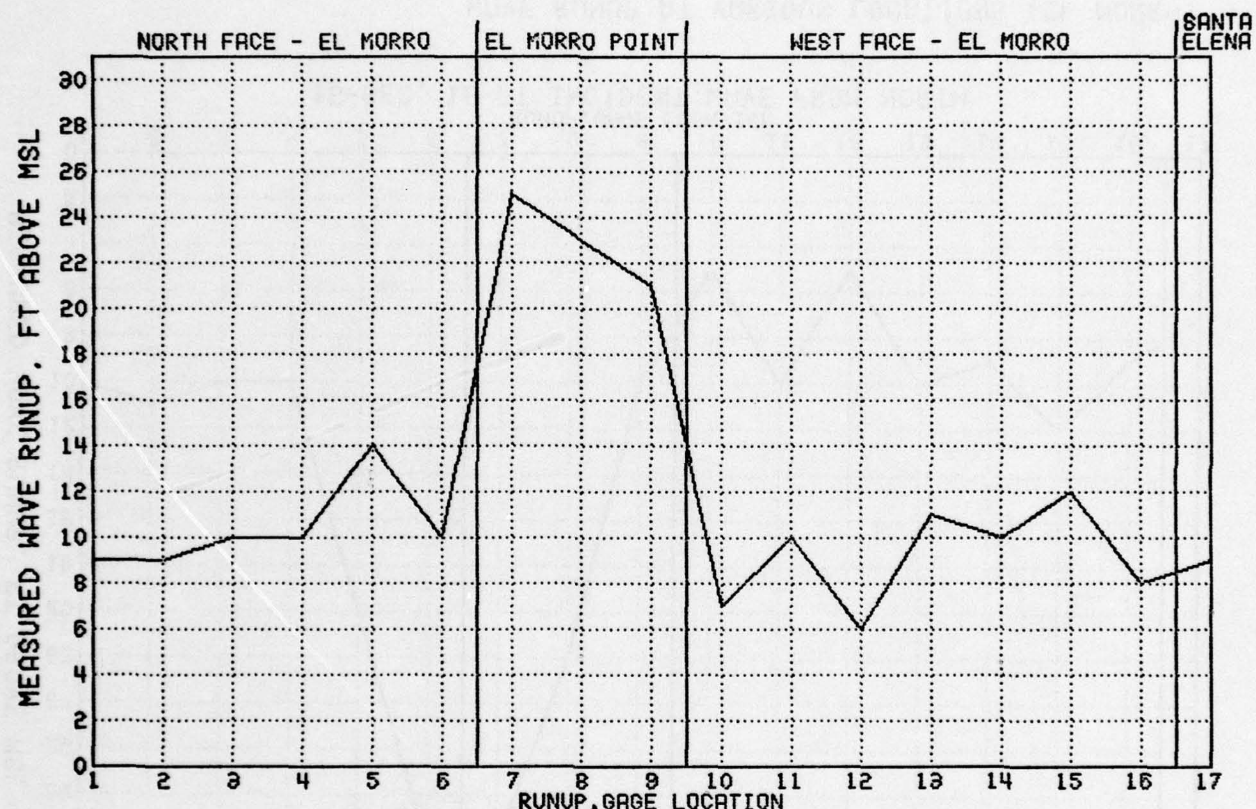
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

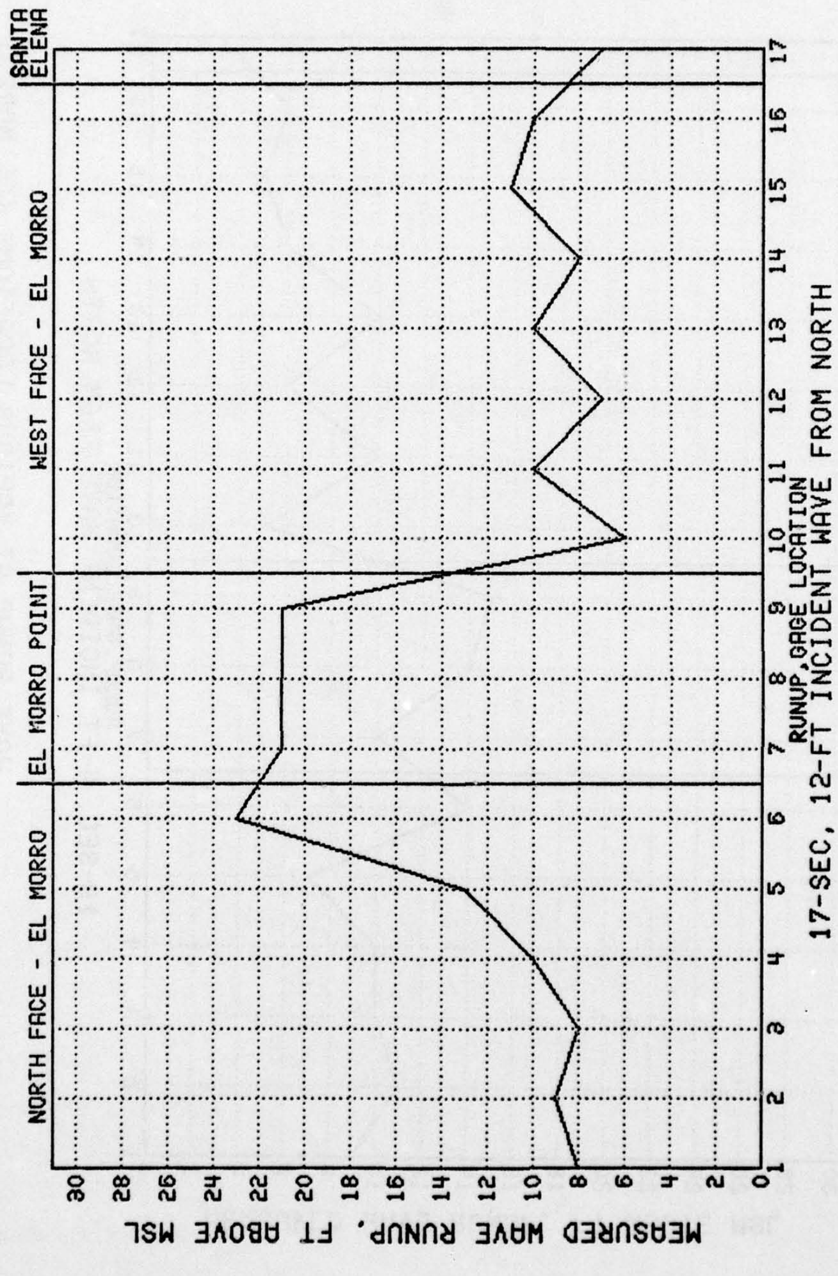


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



17-SEC, 6-FT INCIDENT WAVE FROM NORTH

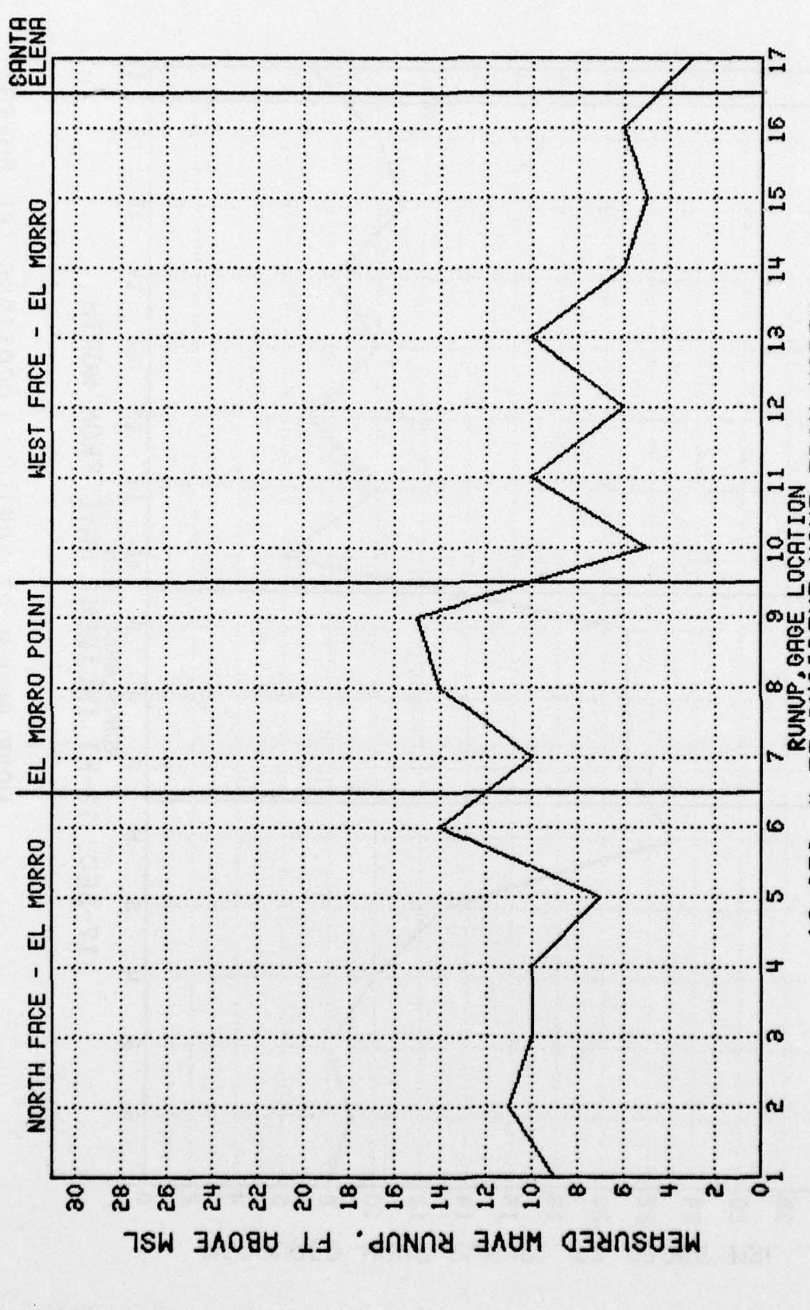
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



17-SEC, 12-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

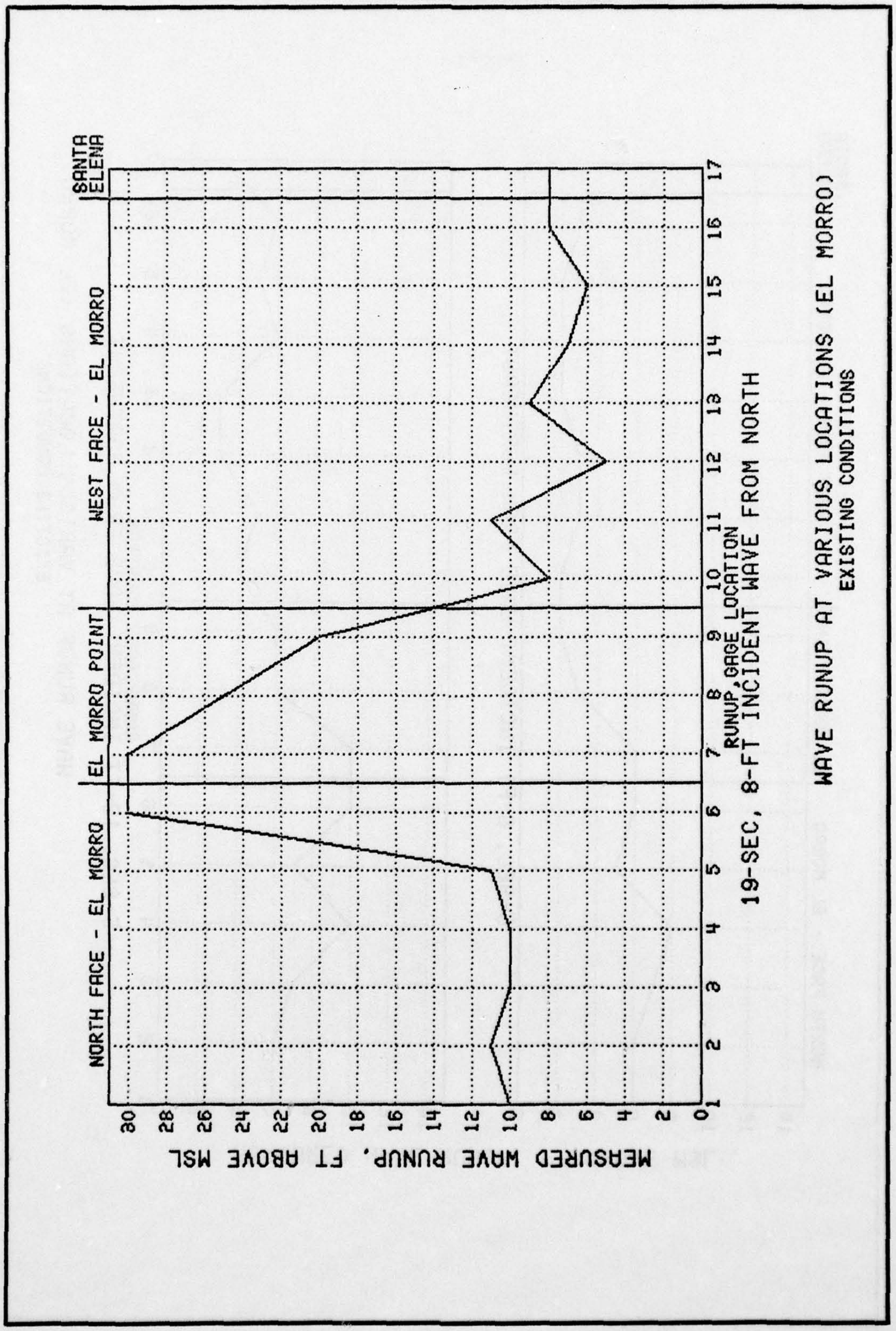
EXISTING CONDITIONS



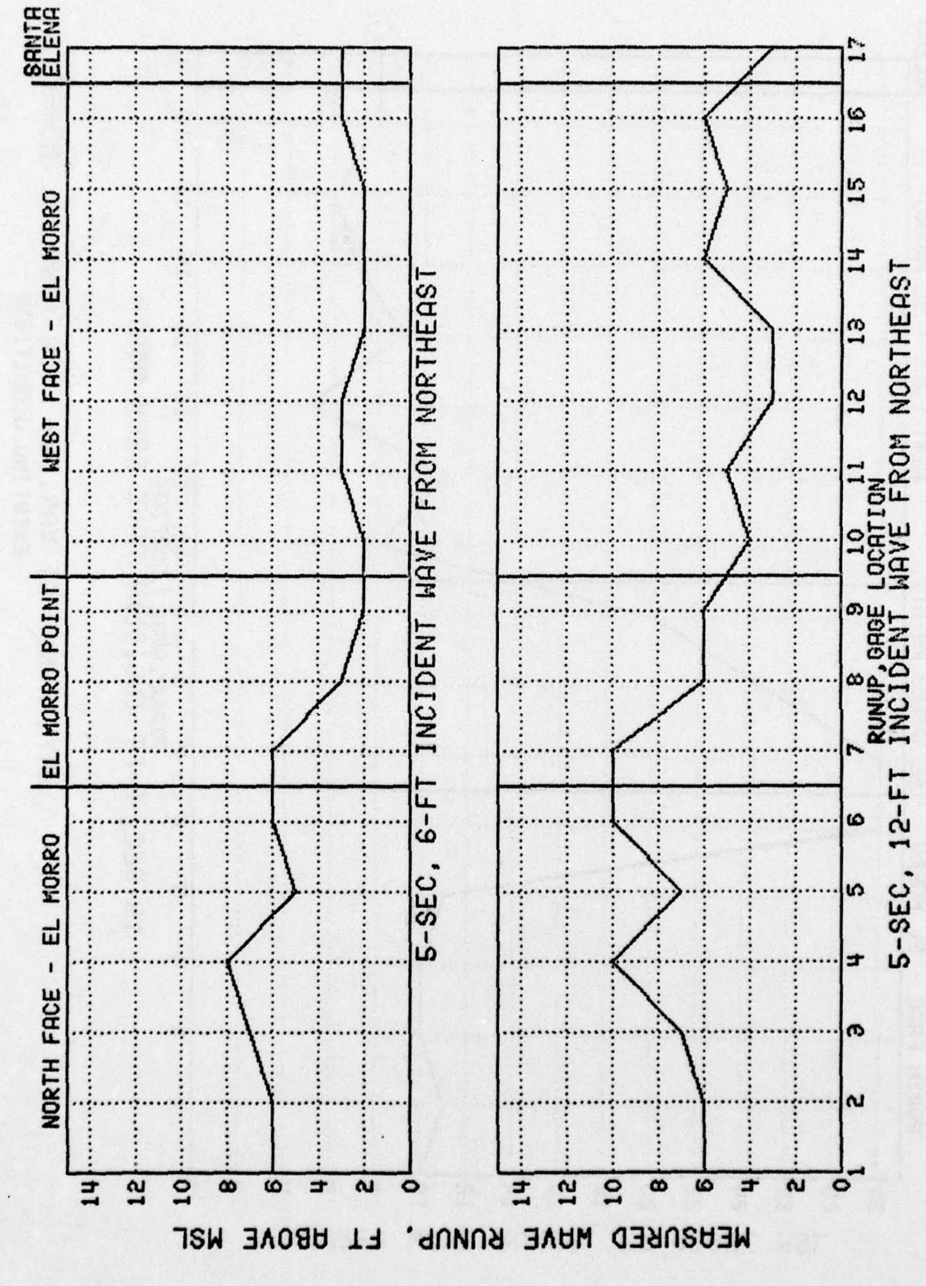
19-SEC, 4-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

PLATE 40

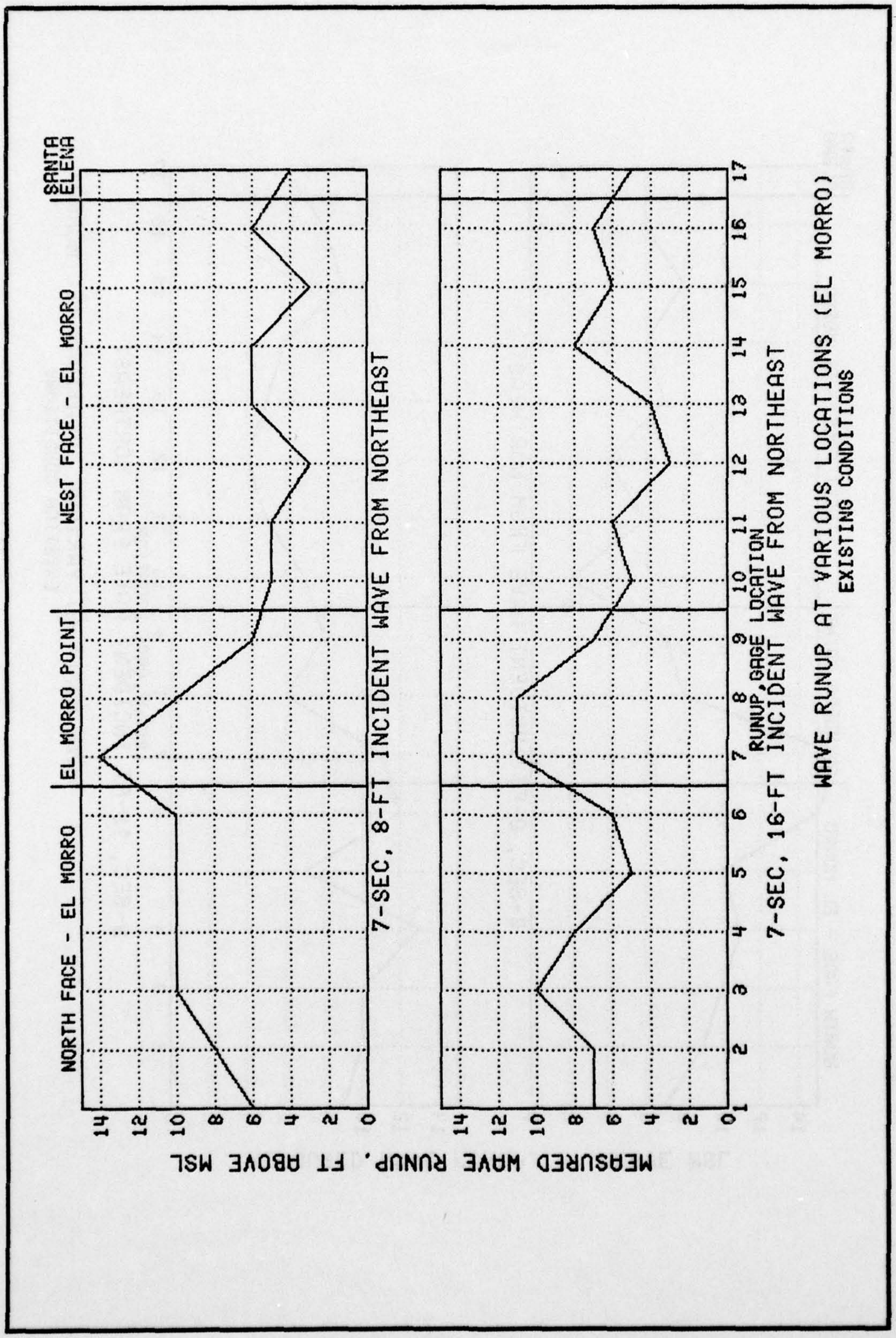


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

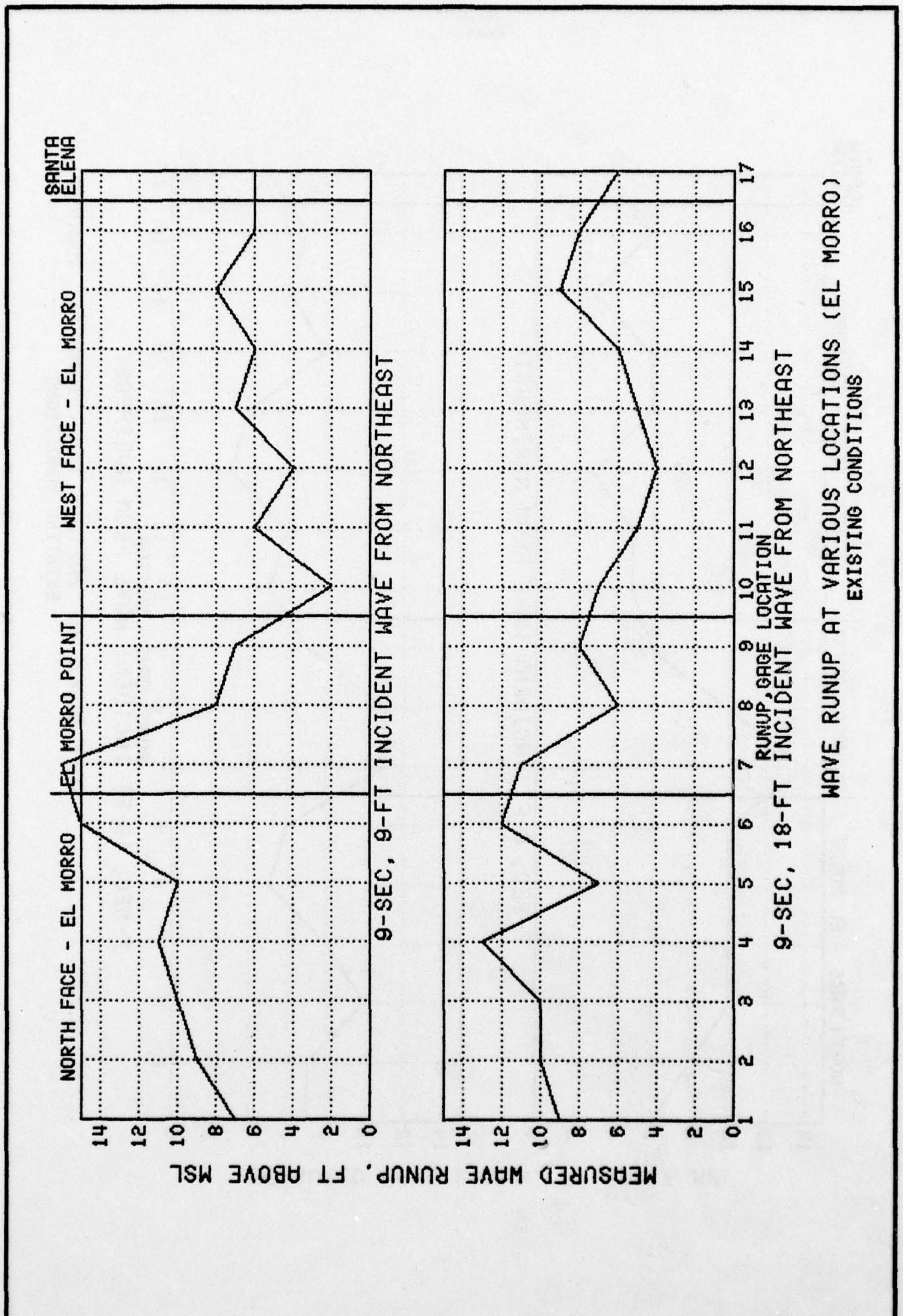


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

PLATE 42

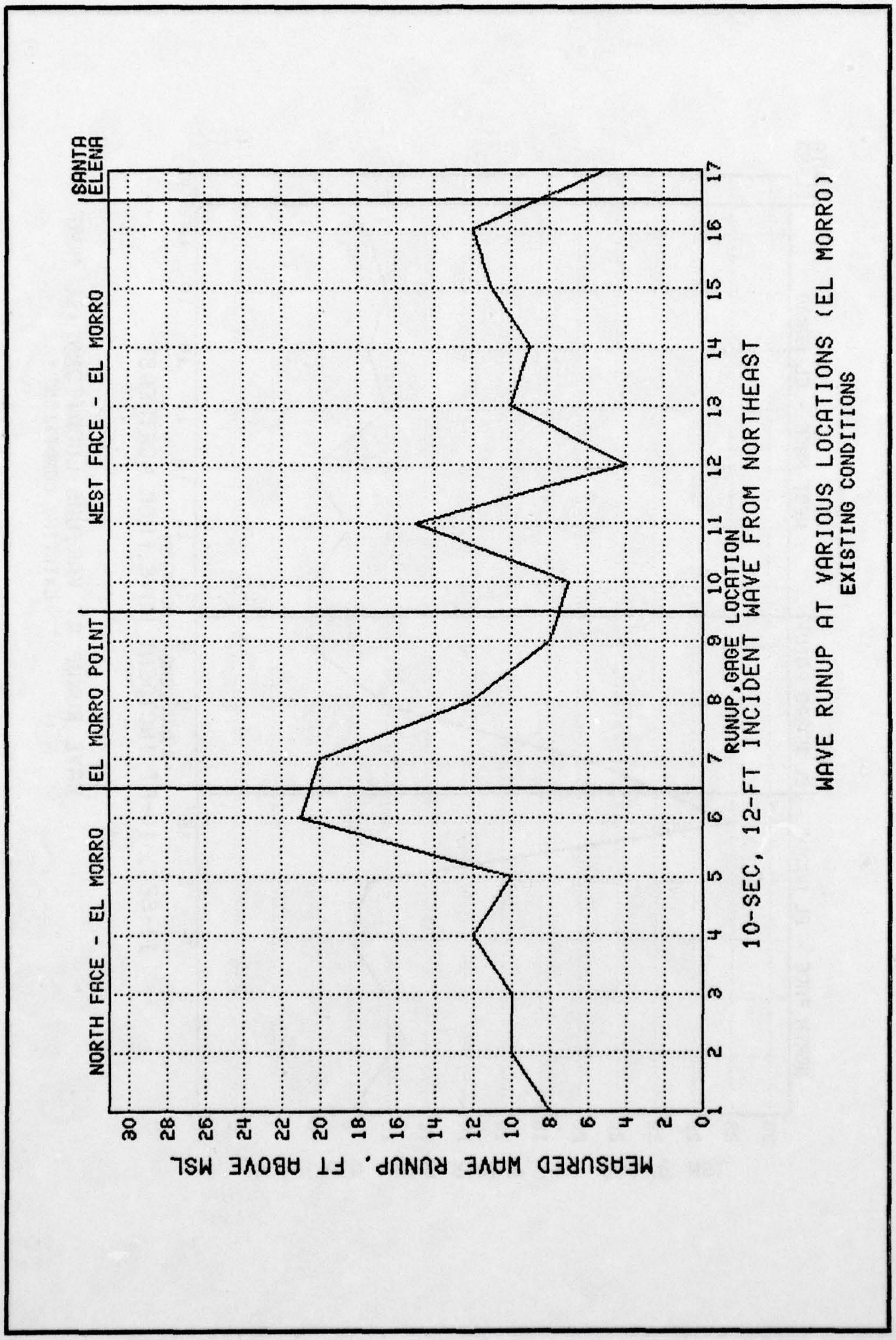


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

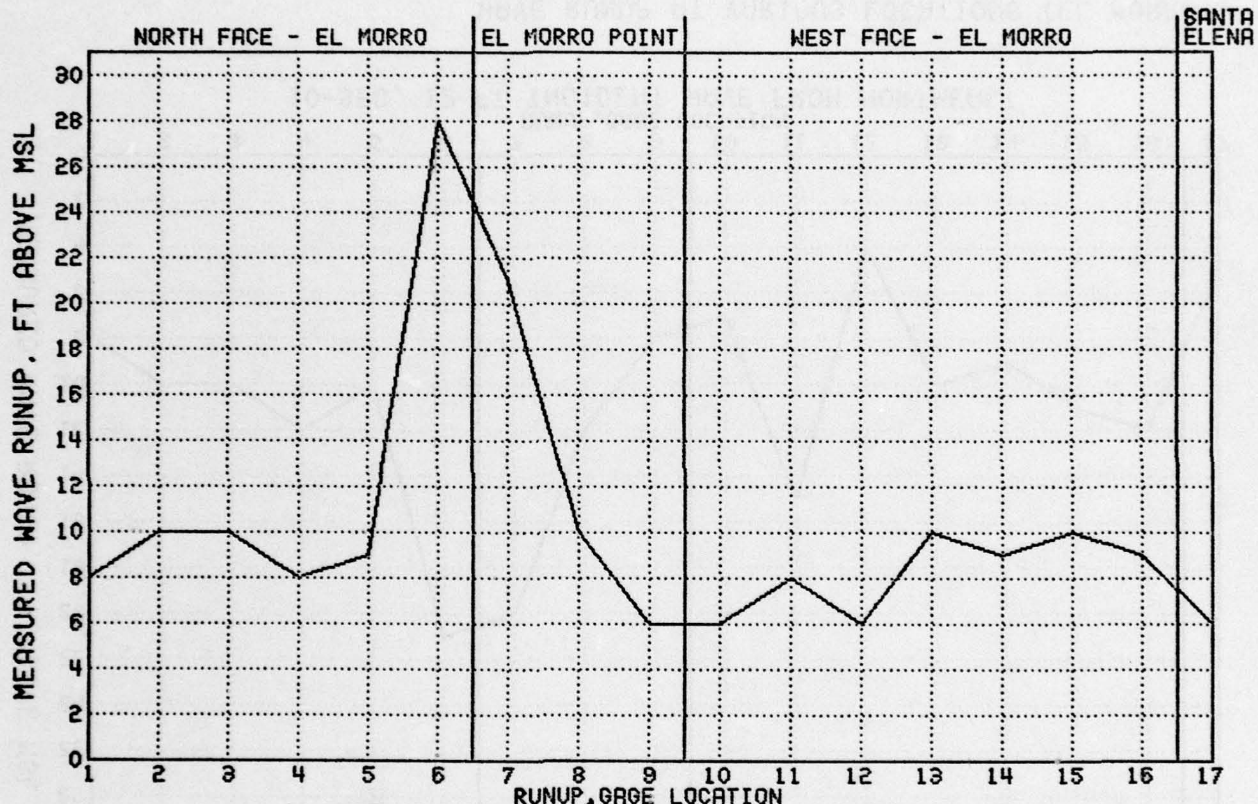


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

PLATE 44

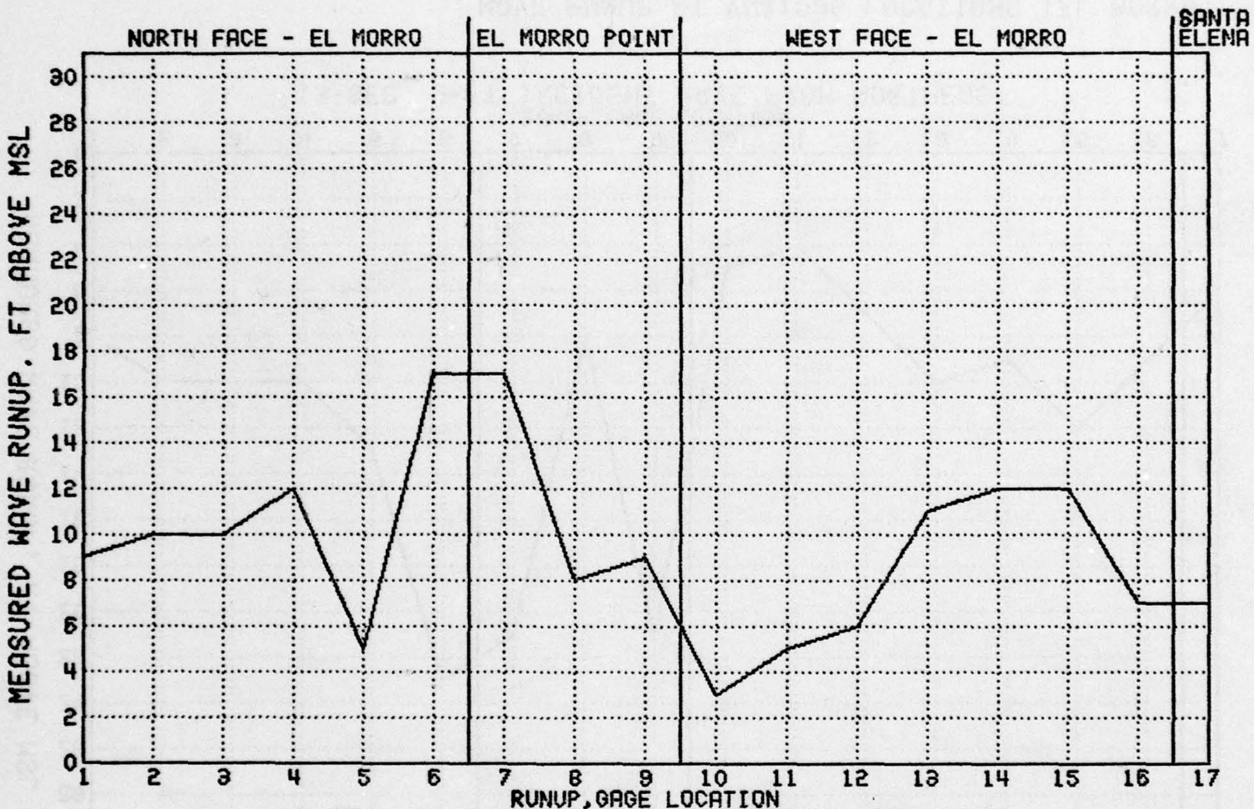


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



11-SEC, 10-FT INCIDENT WAVE FROM NORTHEAST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



11-SEC, 22-FT INCIDENT WAVE FROM NORTHEAST

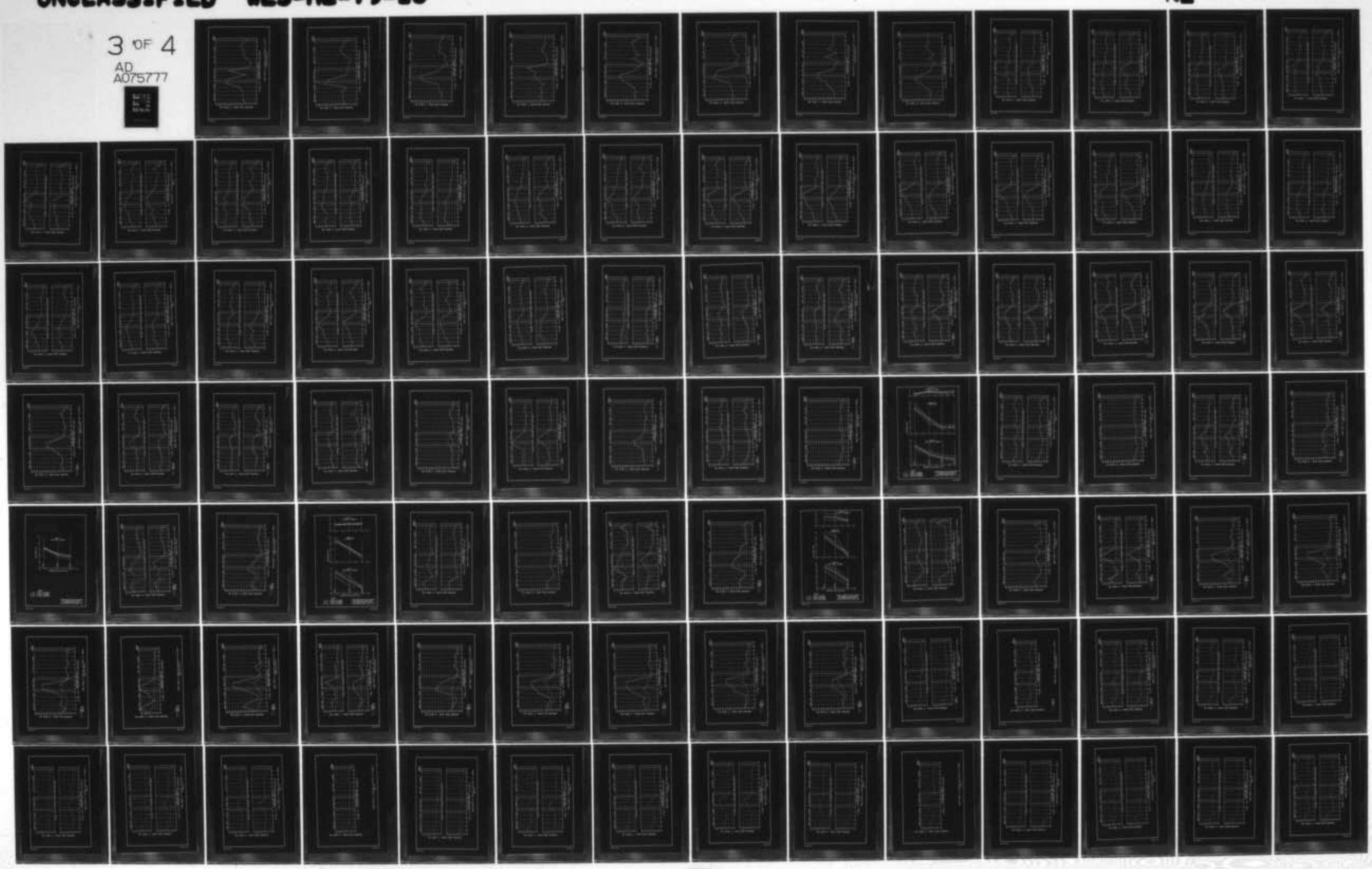
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

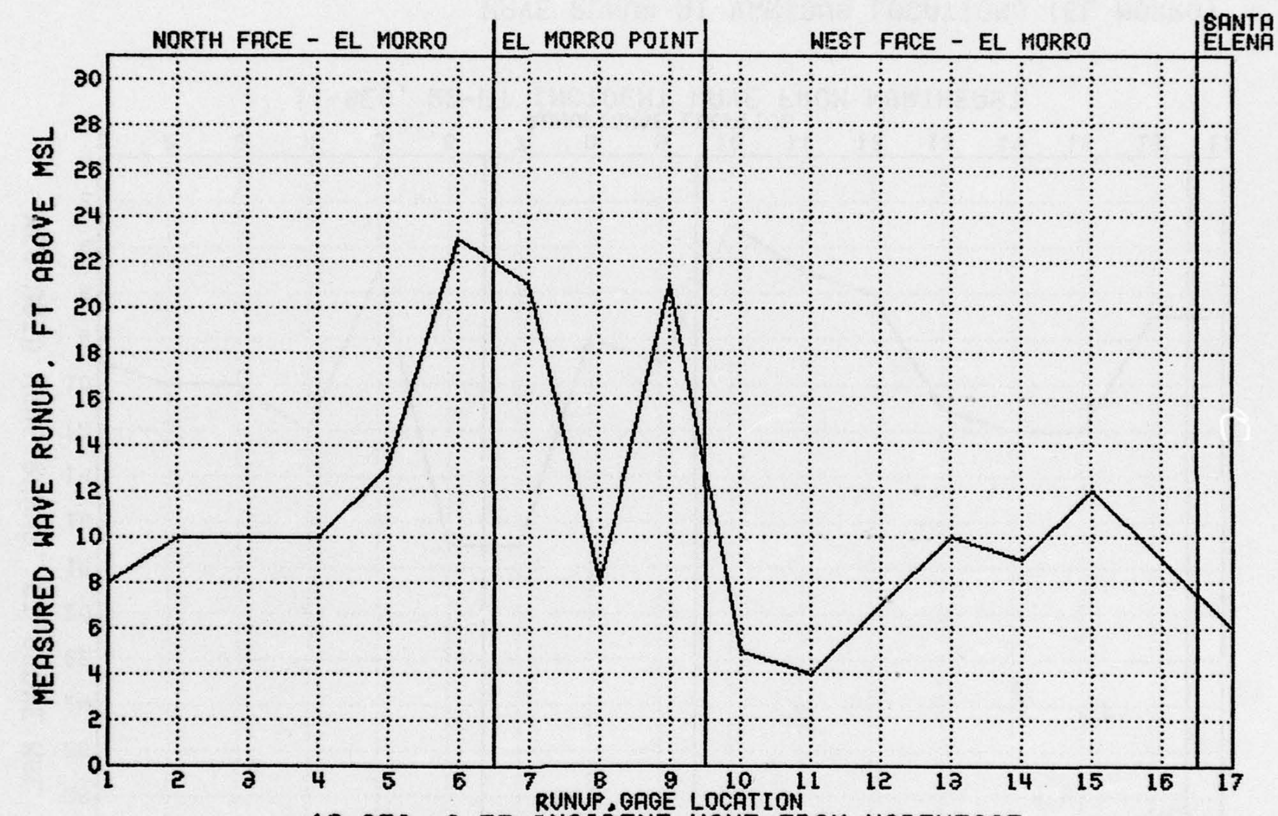
AD-A075 777 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
SAN JUAN NATIONAL HISTORIC SITE, SAN JUAN, PUERTO RICO: DESIGN --ETC(U)
SEP 79 R R BOTTIN

UNCLASSIFIED WES-HL-79-15 NL

3 OF 4

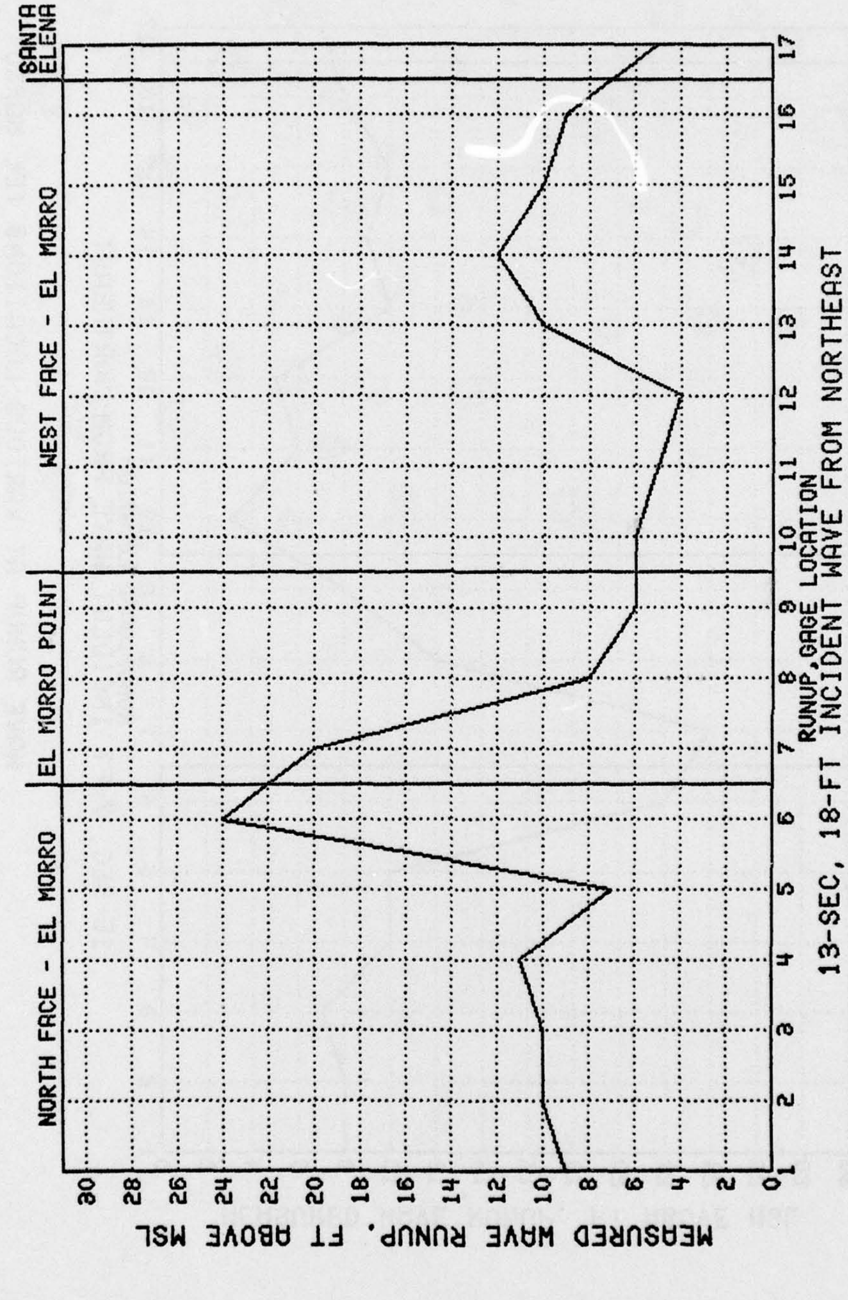
AD
A075777



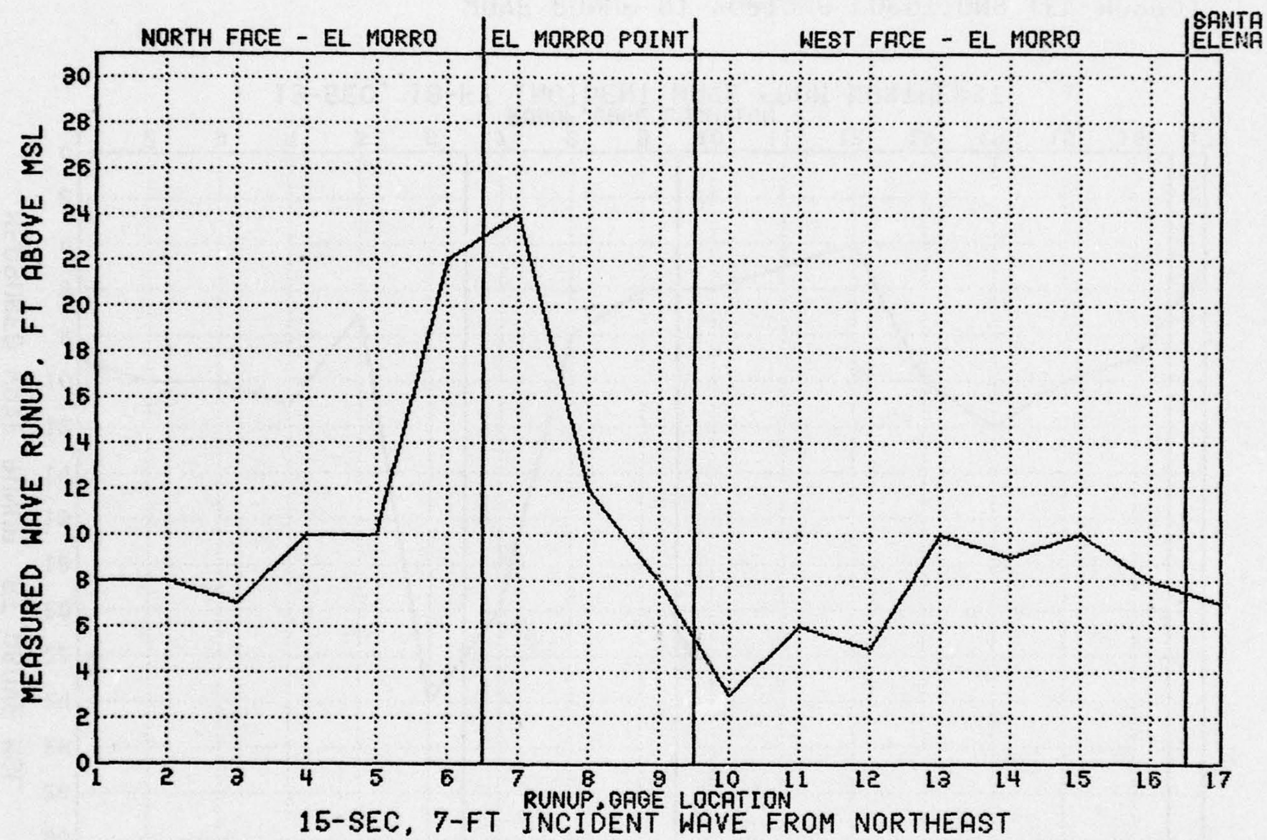


13-SEC, 9-FT INCIDENT WAVE FROM NORTHEAST

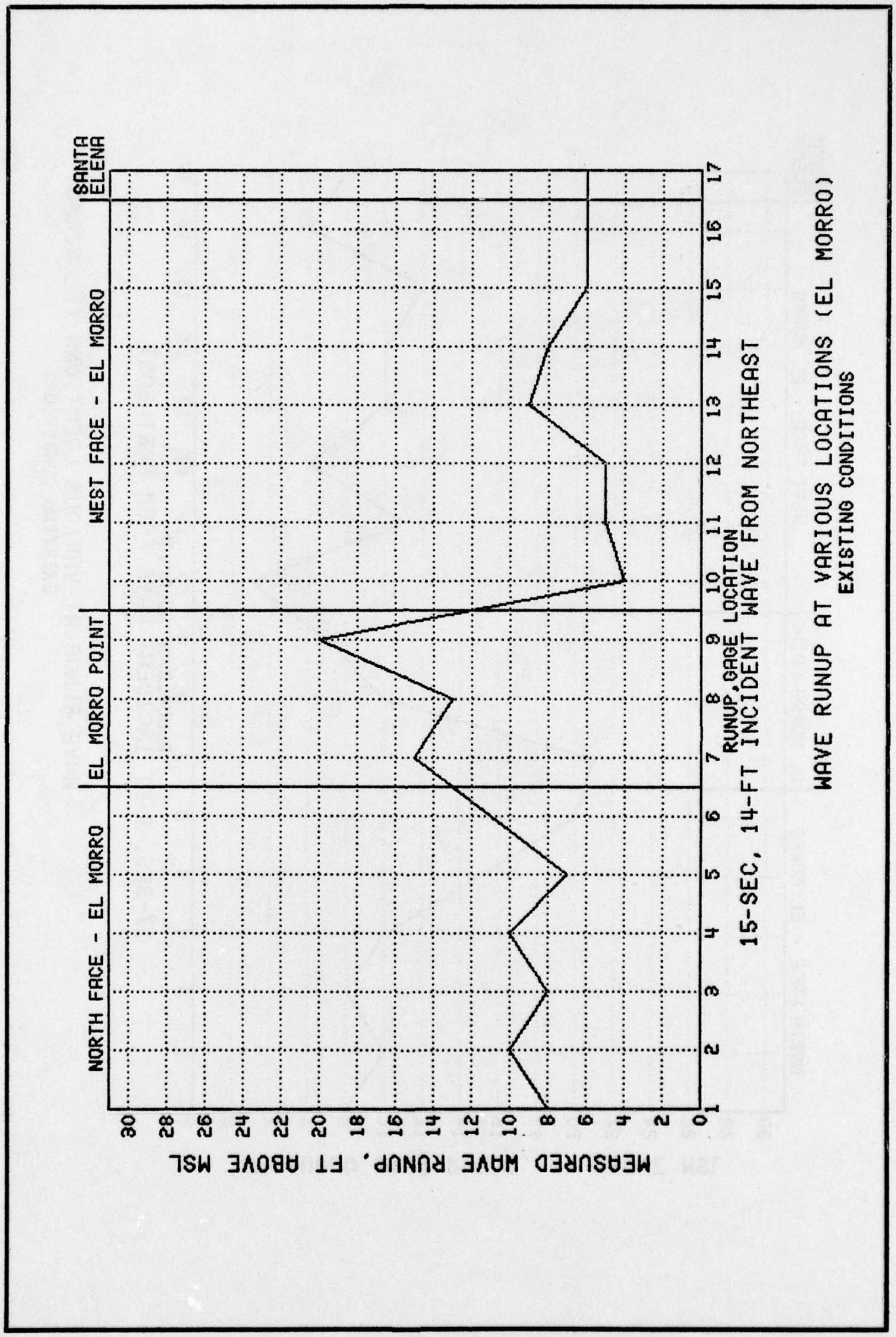
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

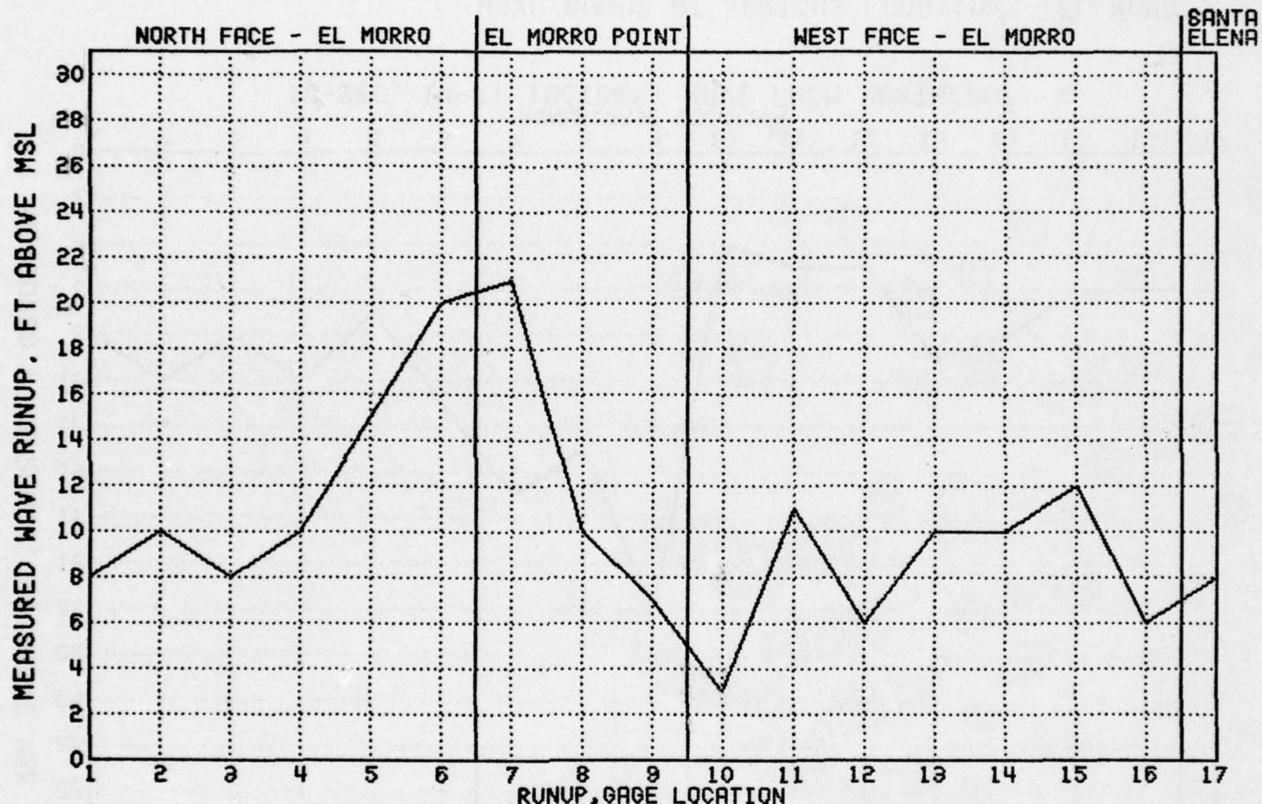


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



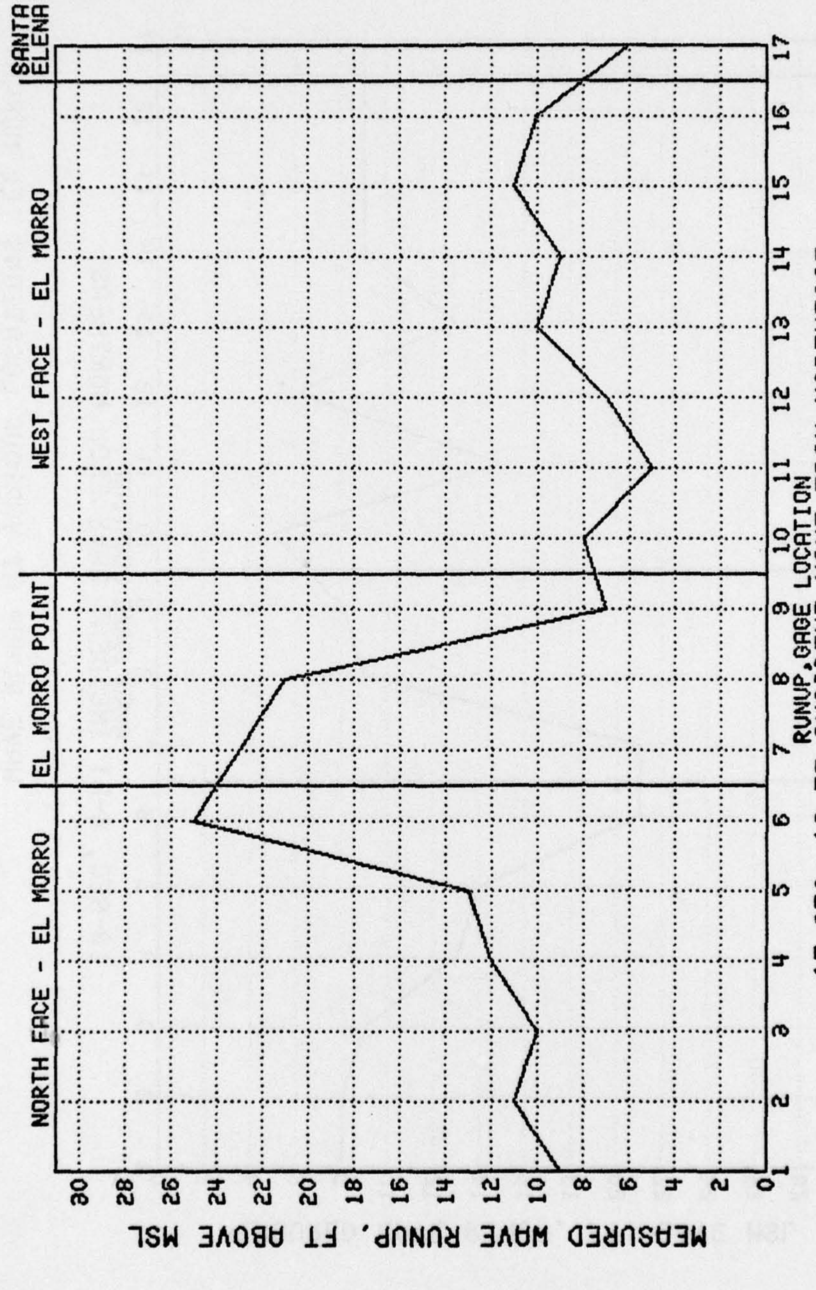
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
15-SEC, 14-FT INCIDENT WAVE FROM NORTHEAST
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



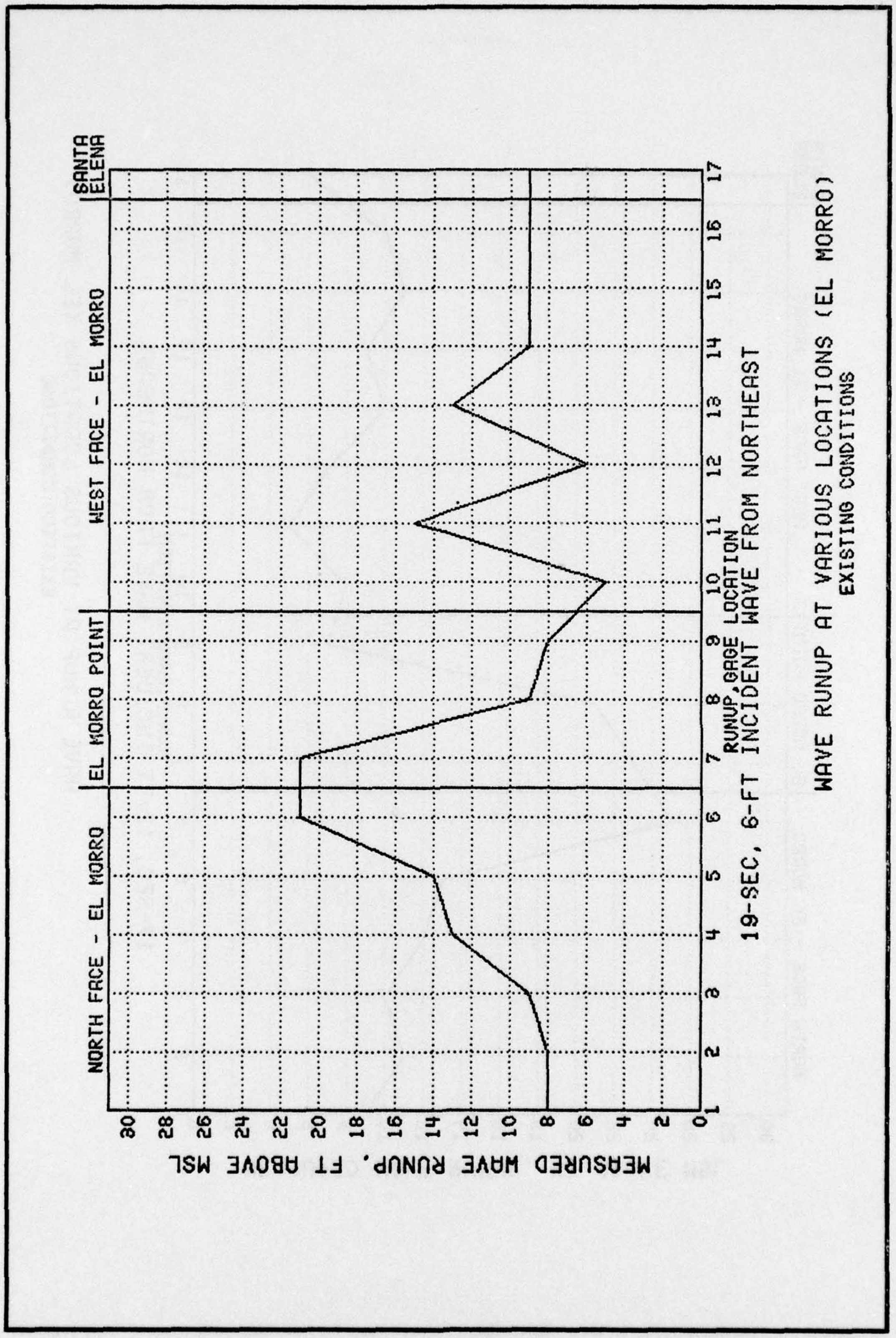
17-SEC, 6-FT INCIDENT WAVE FROM NORTHEAST

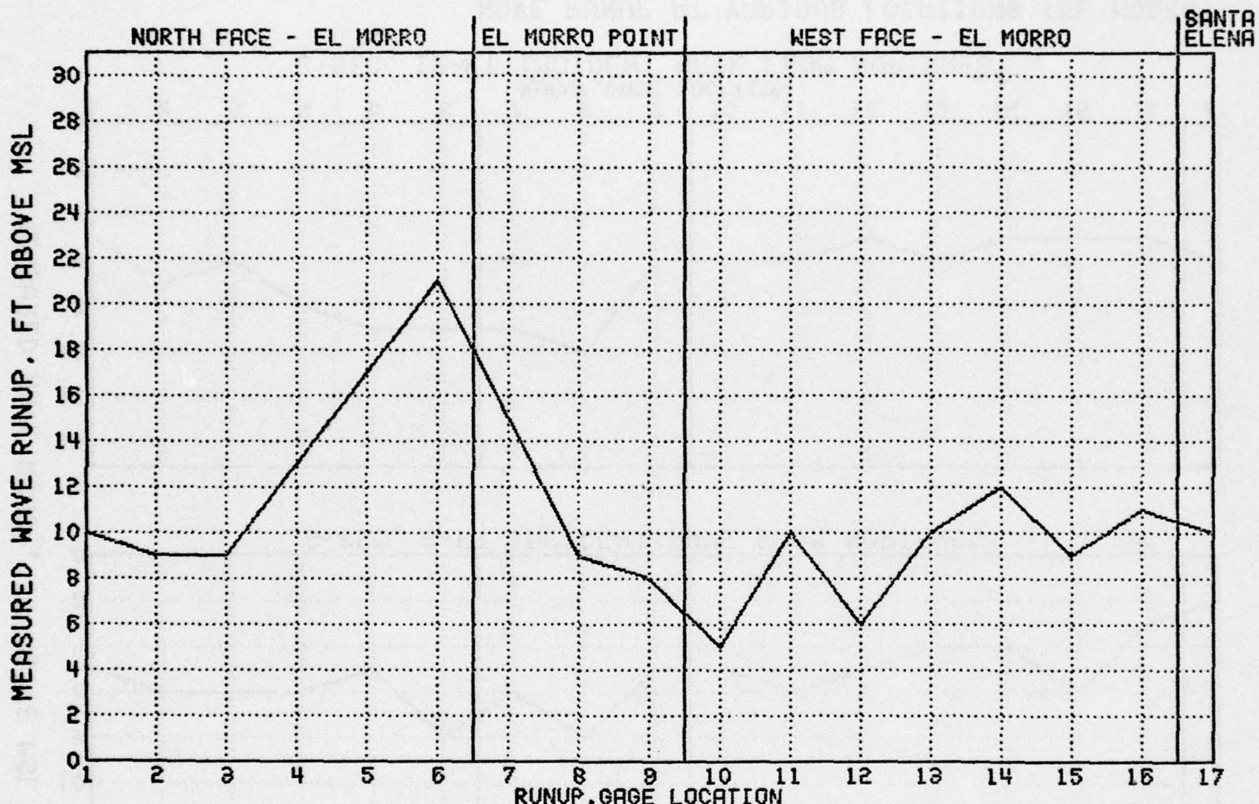
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS



17-SEC, 12-FT INCIDENT WAVE FROM NORTHEAST

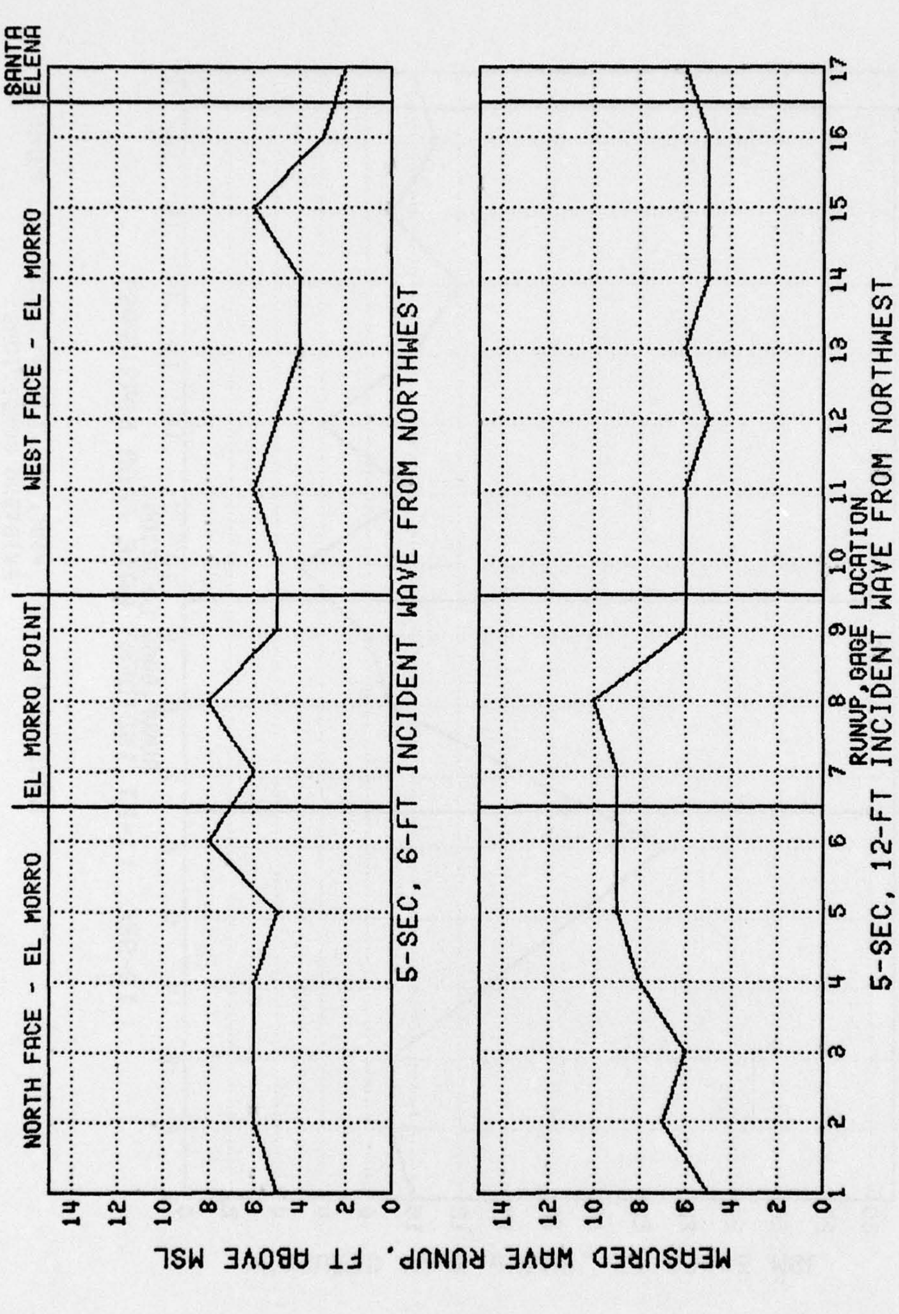
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP,GAGE LOCATION
19-SEC, 6-FT INCIDENT WAVE FROM NORTHEAST
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

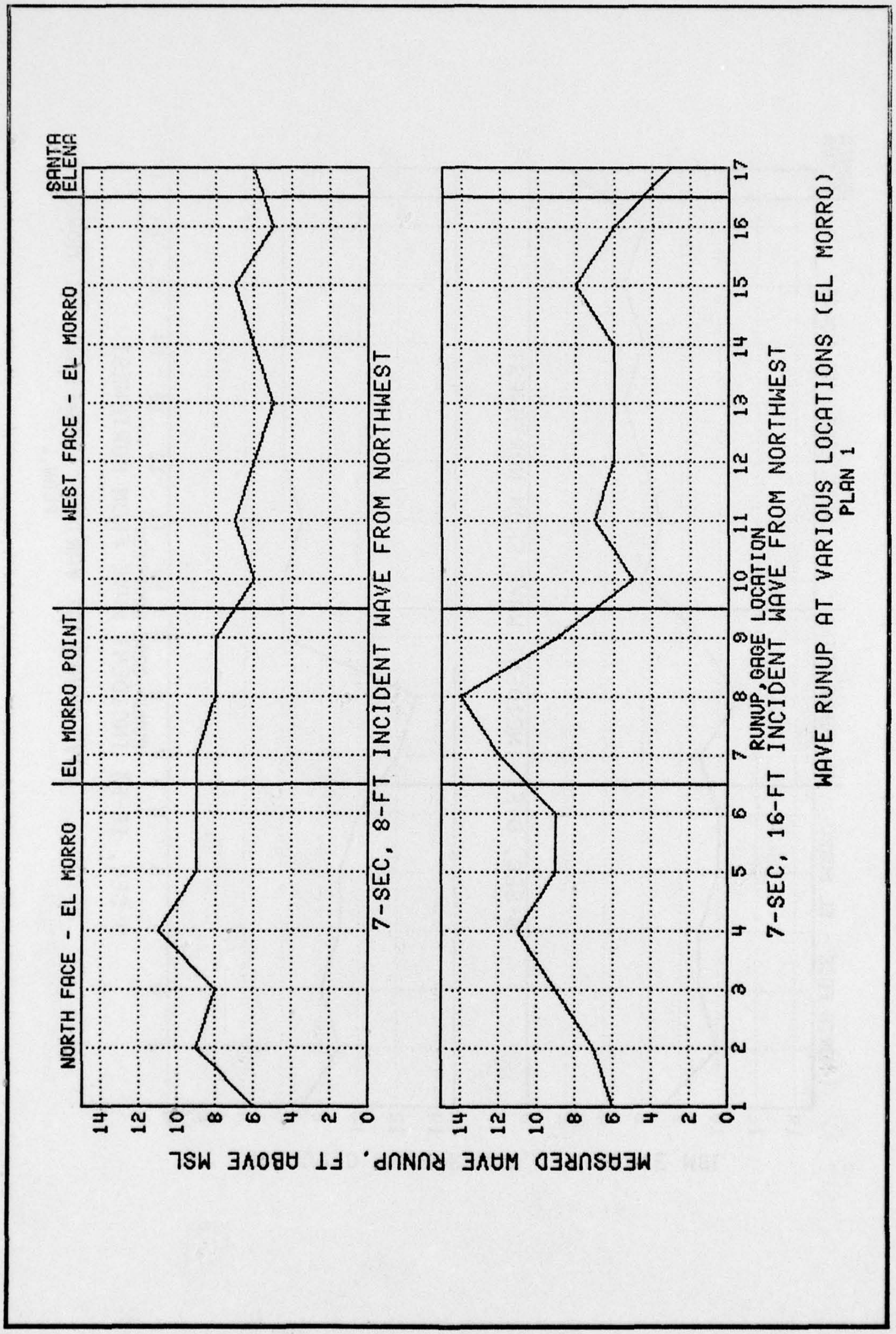


19-SEC, 11-FT INCIDENT WAVE FROM NORTHEAST

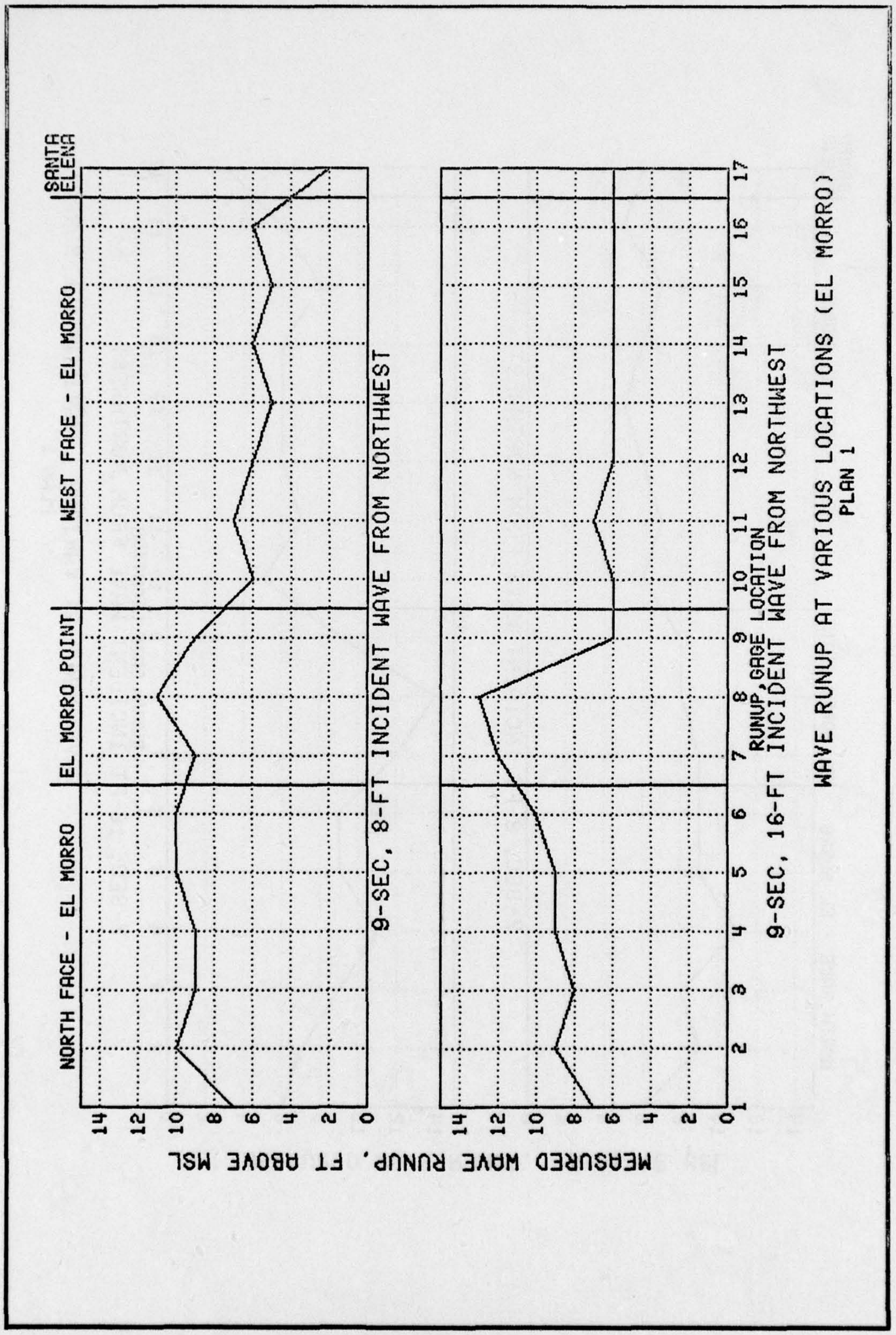
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS

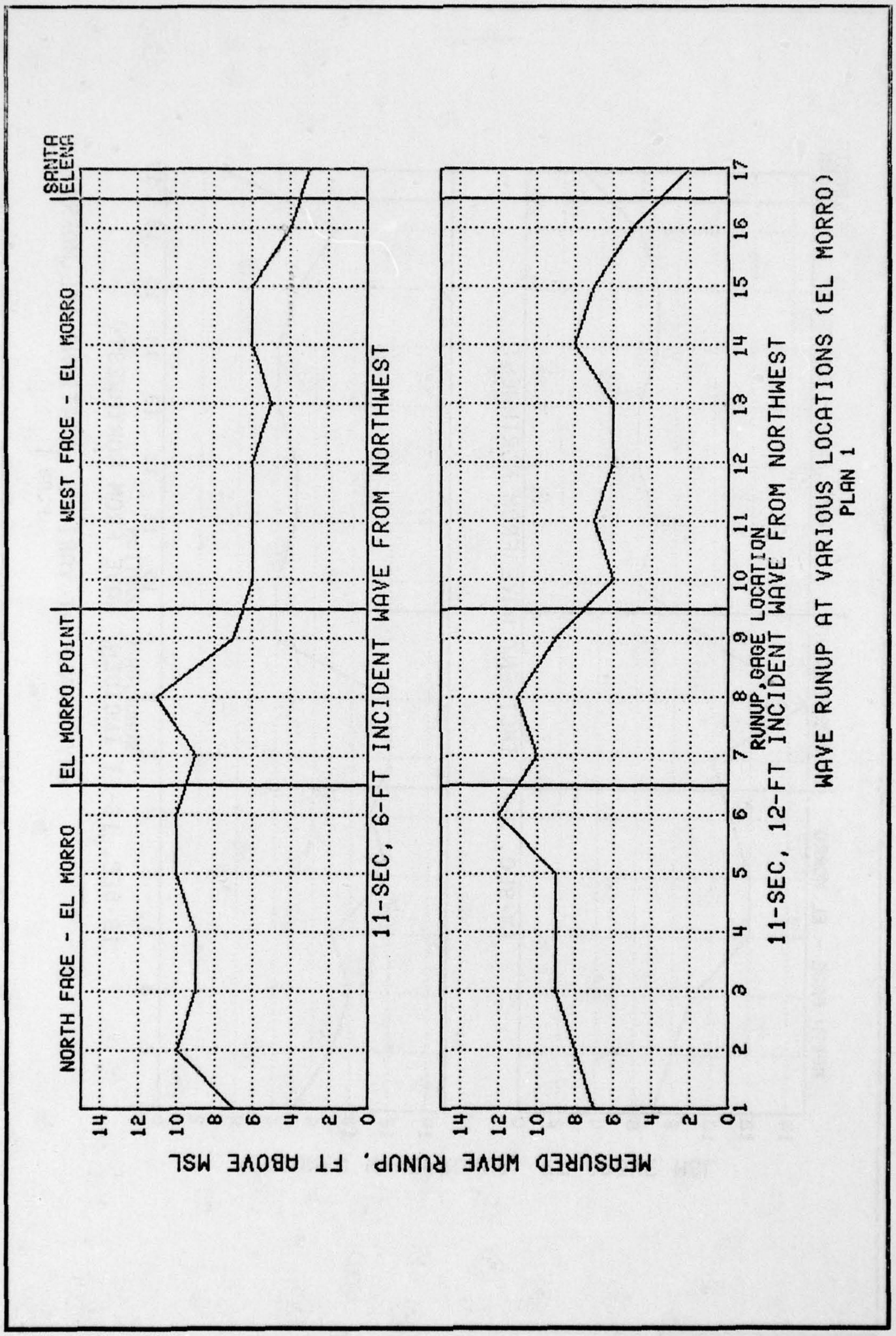


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

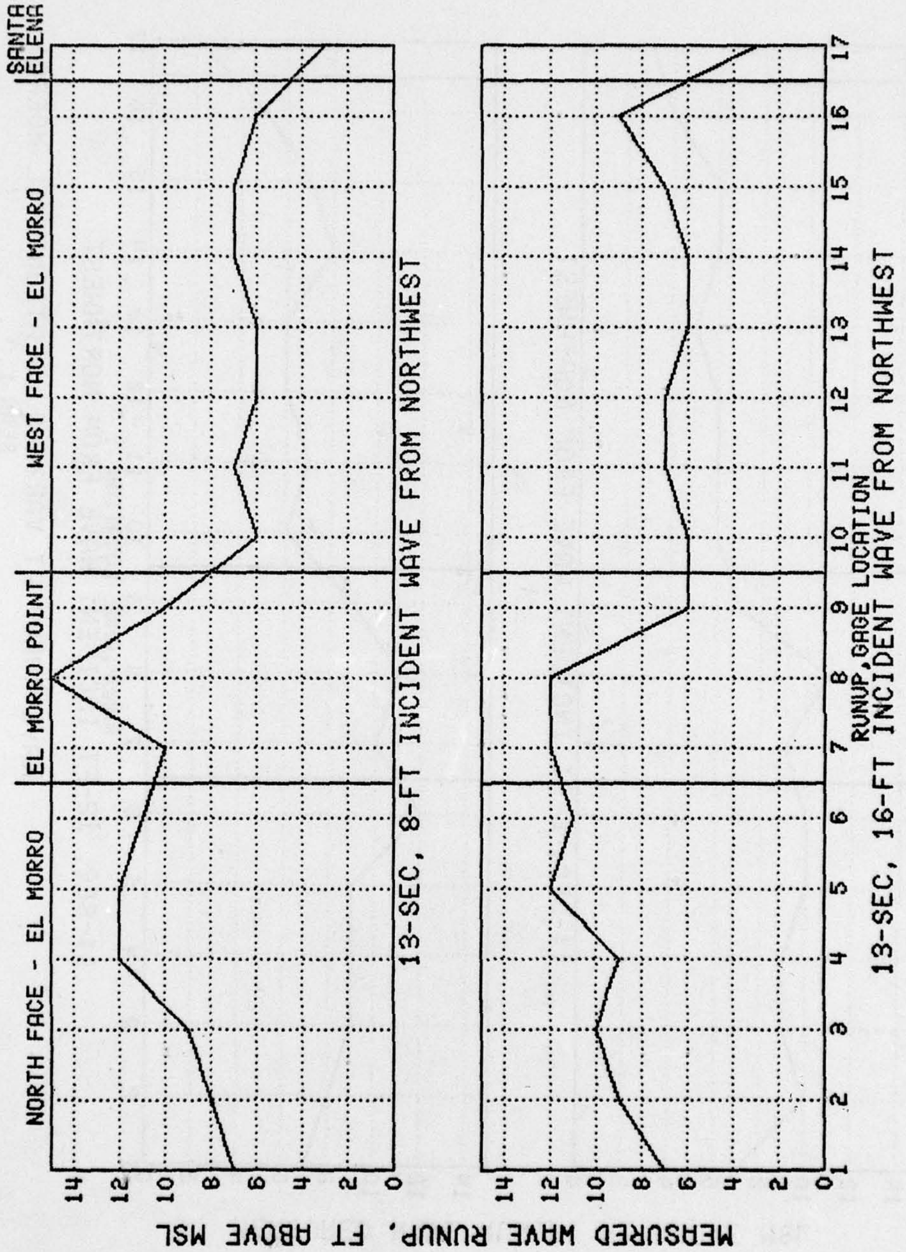


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

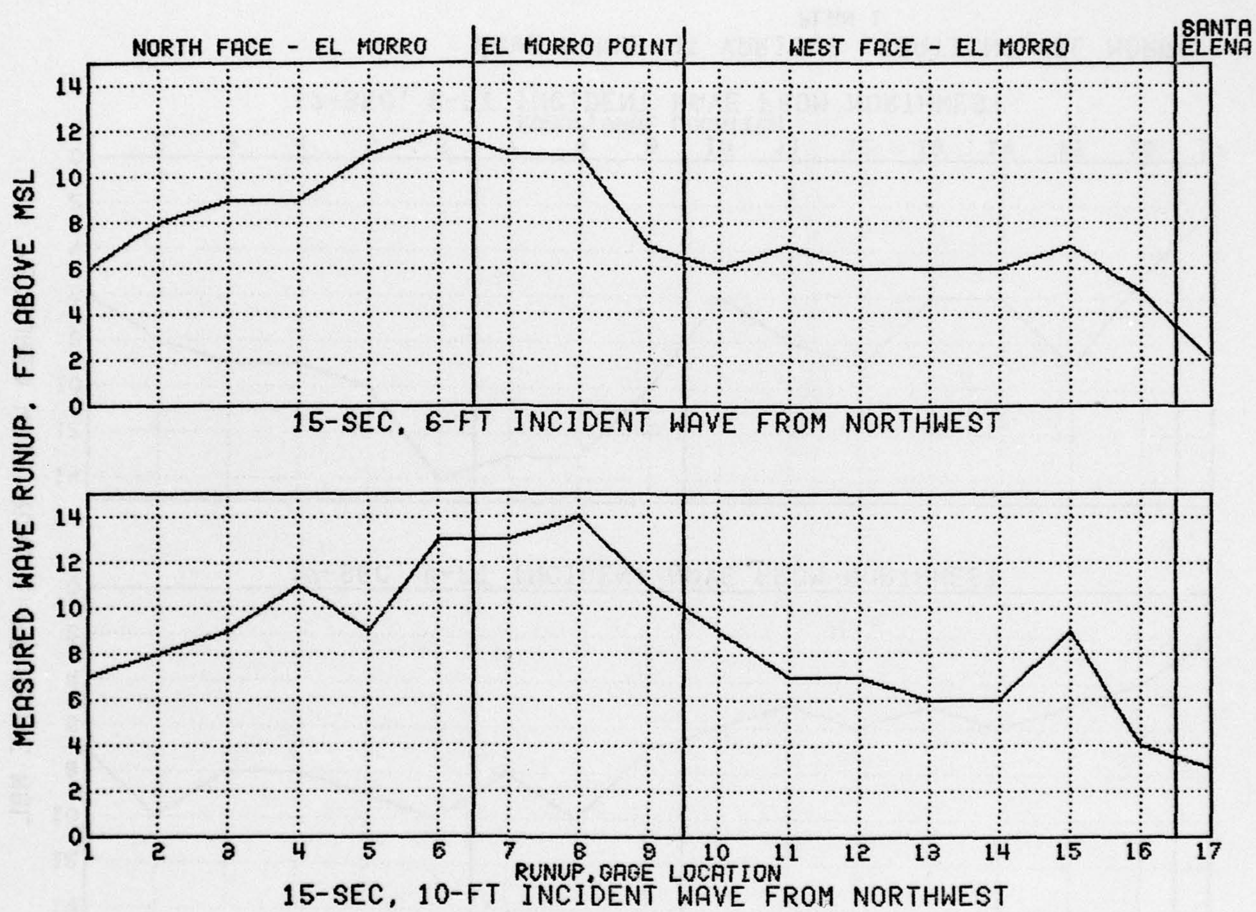

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
9-SEC, 8-FT INCIDENT WAVE FROM NORTHWEST
9-SEC, 16-FT INCIDENT WAVE FROM NORTHWEST
MEASURED WAVE RUNUP, FT ABOVE MSL
RUNUP GAGE LOCATION
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



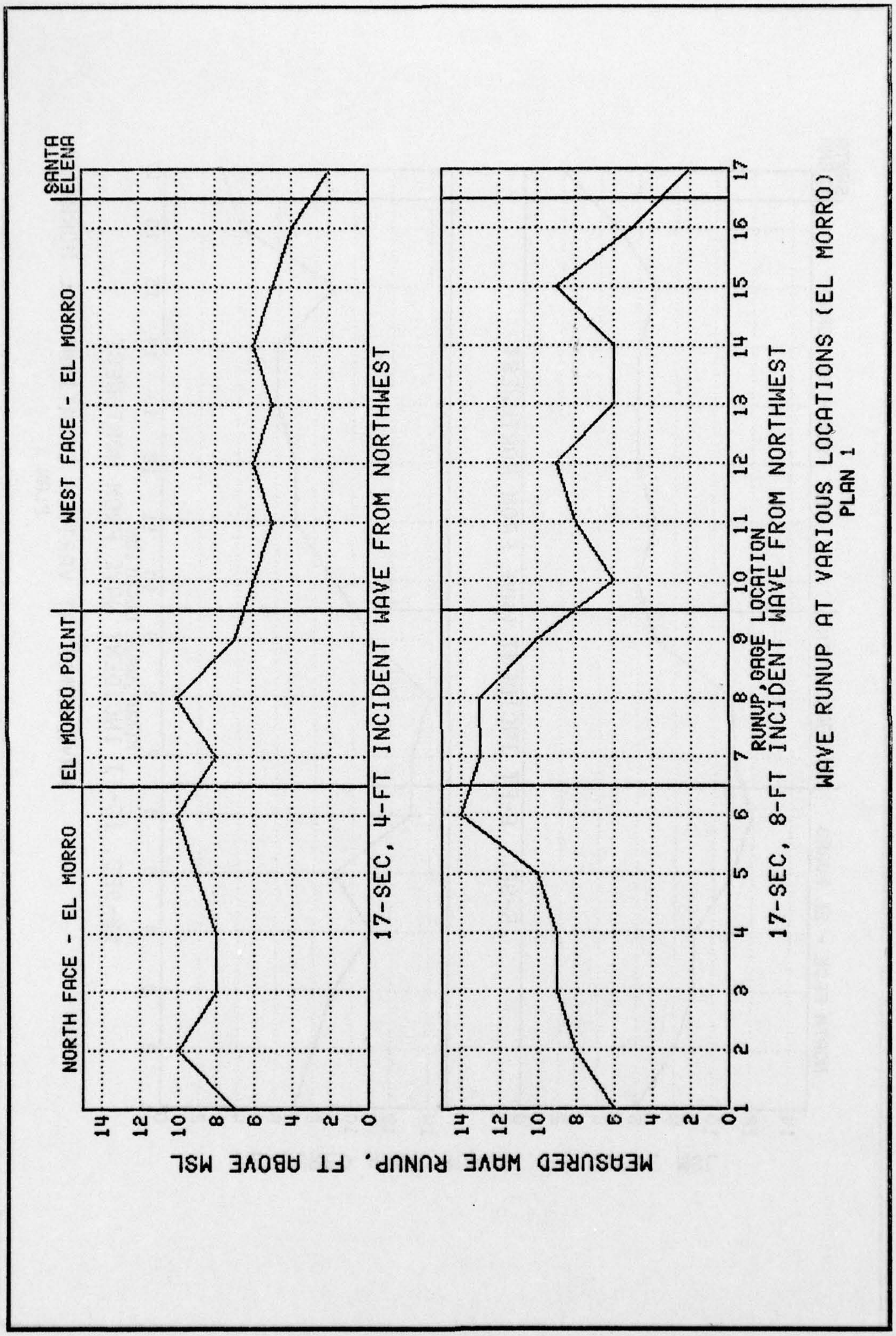
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



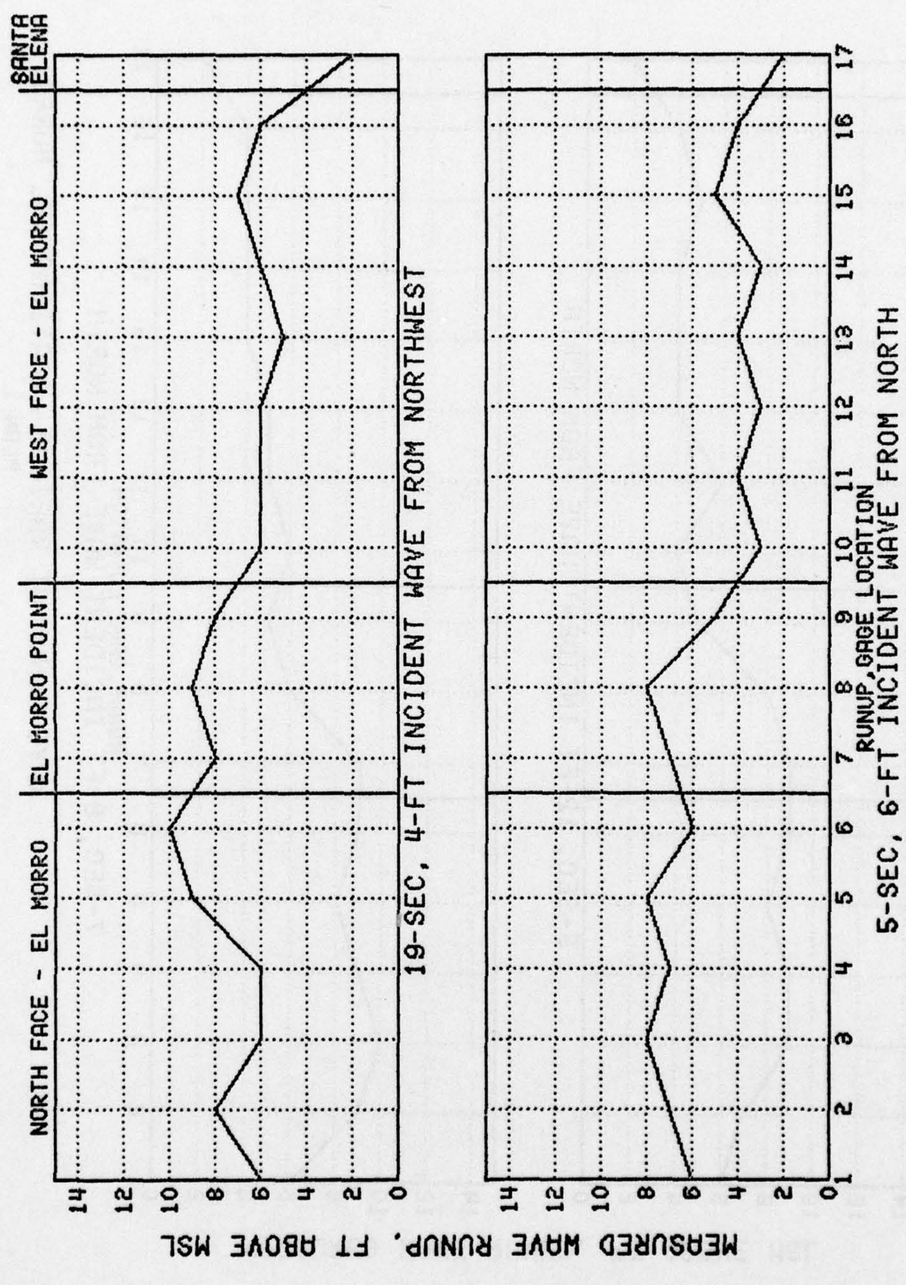
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



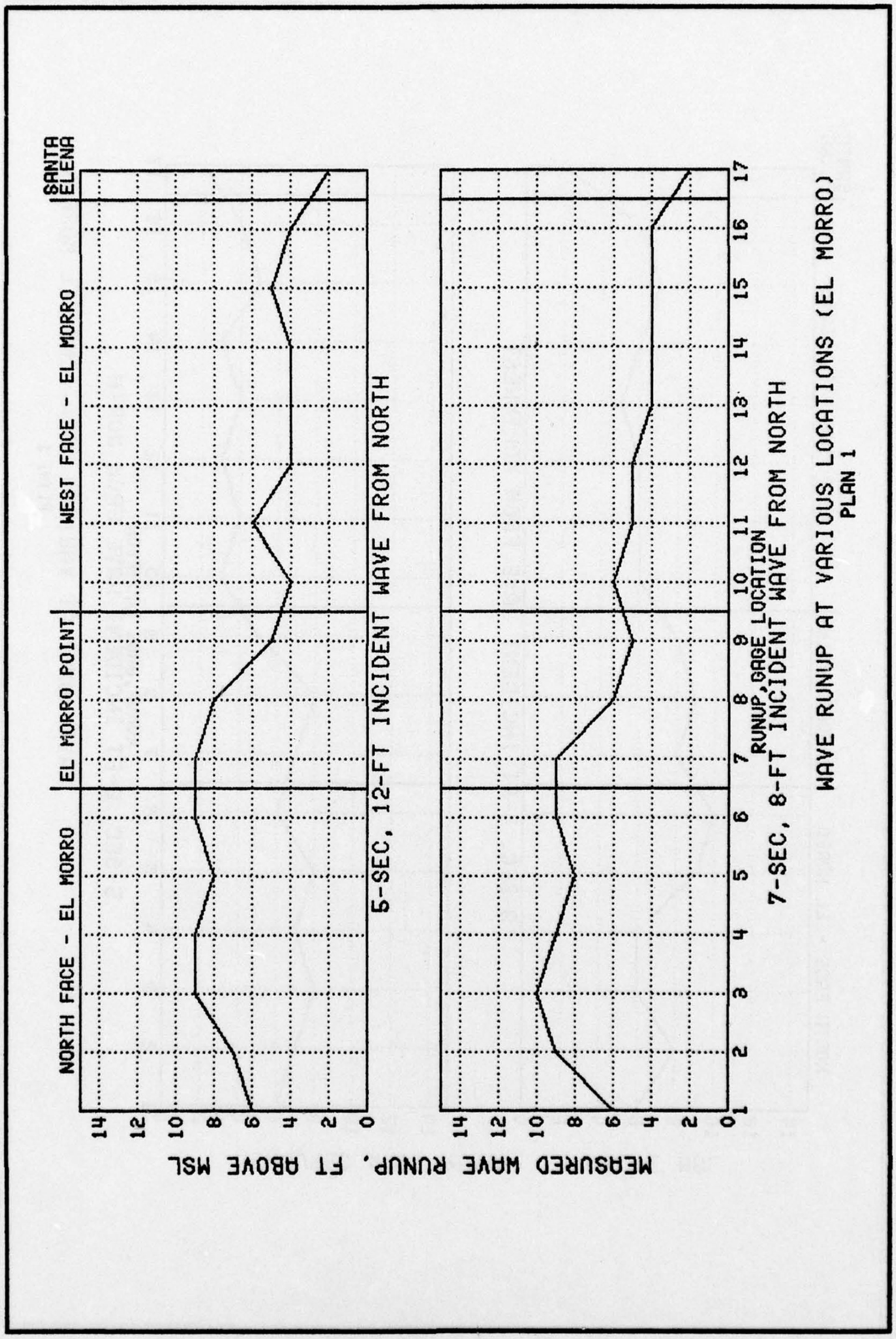
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

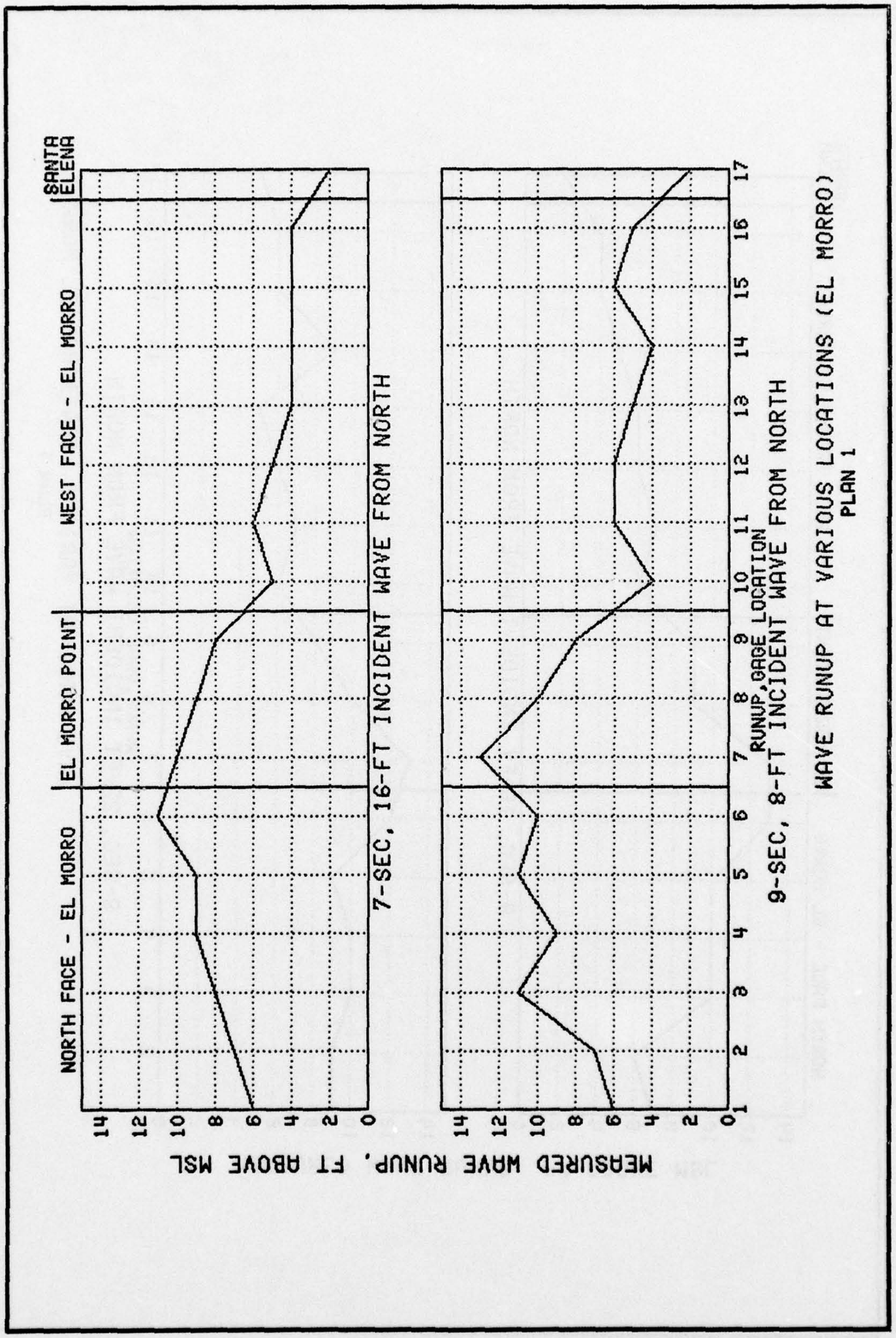


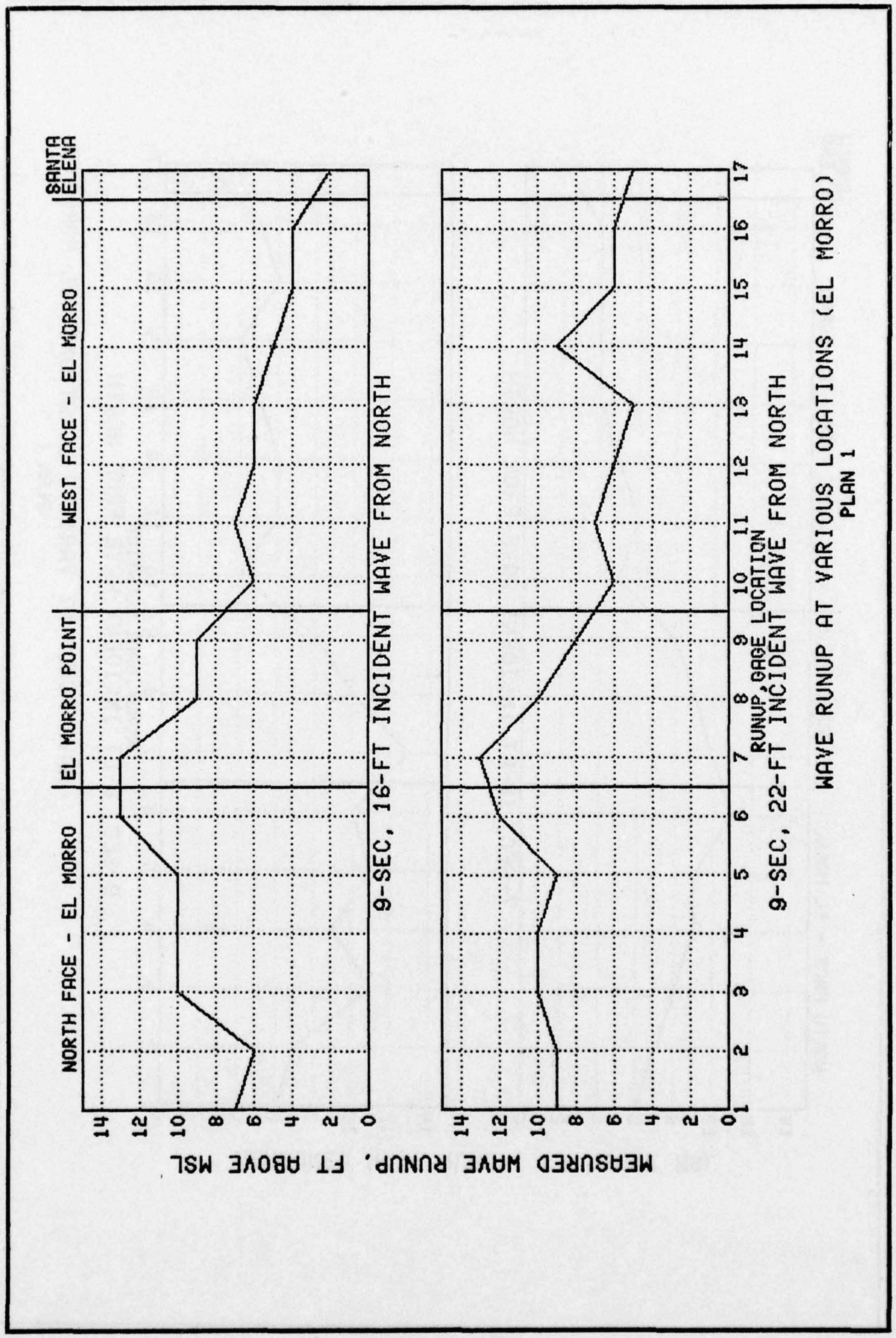
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

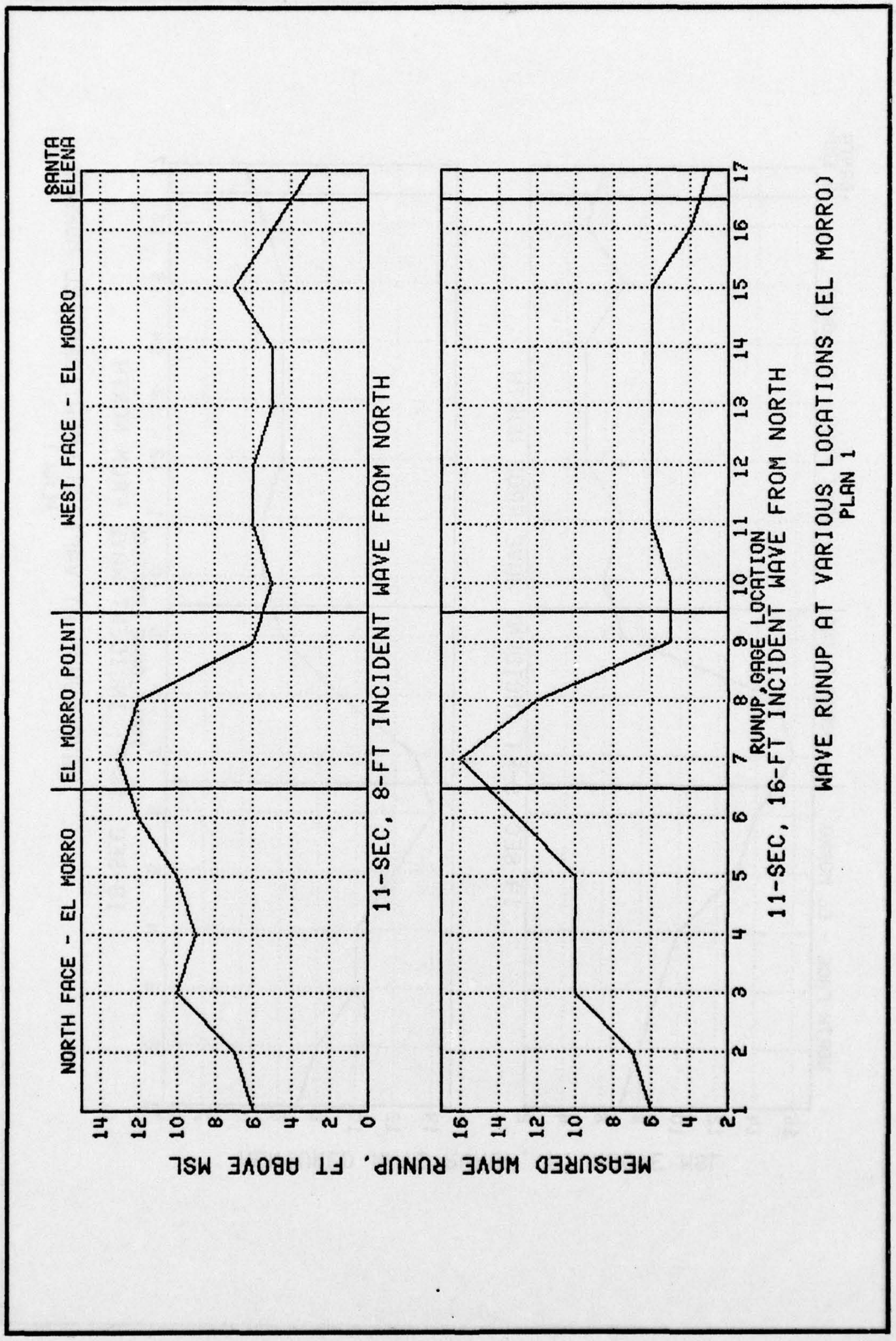


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

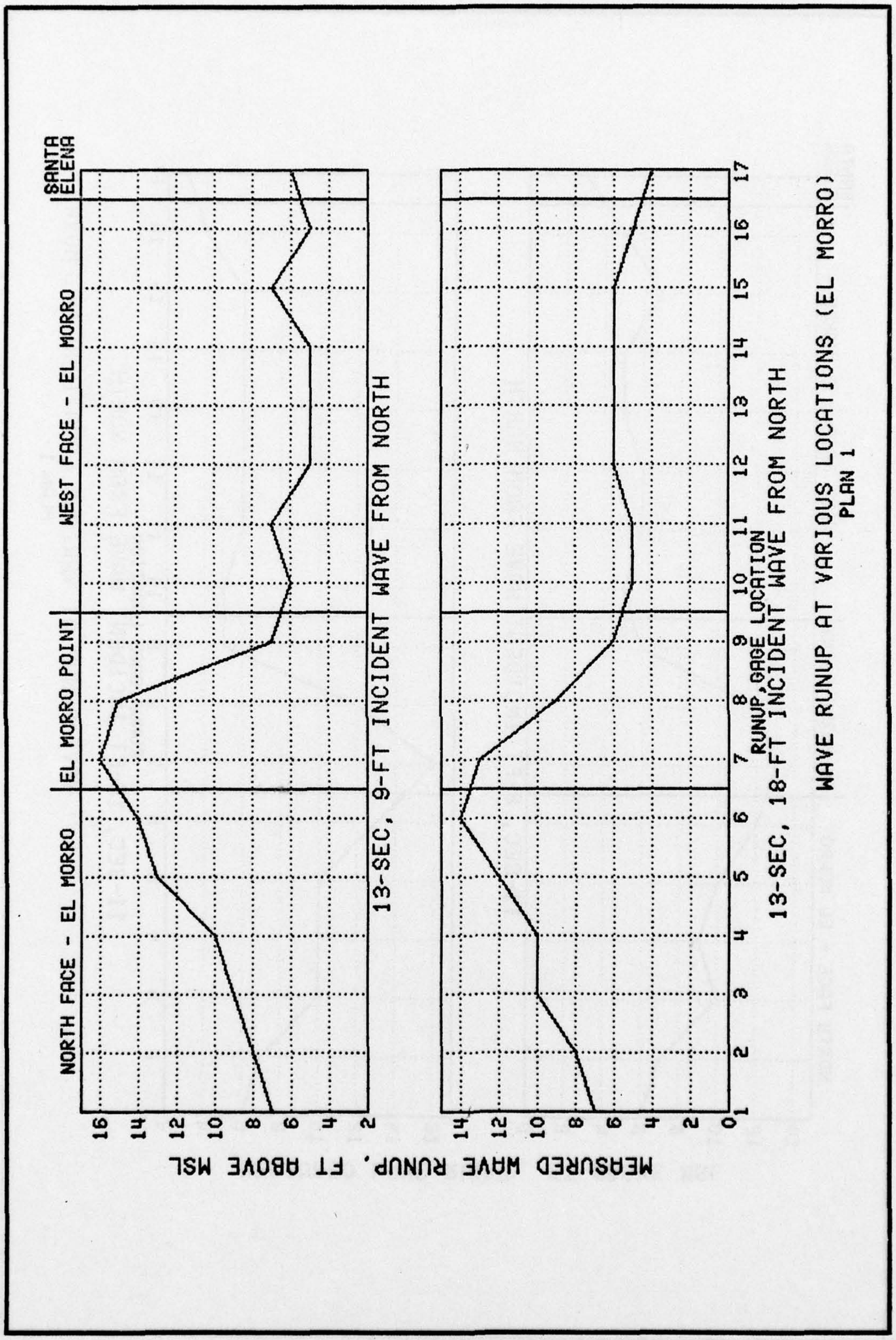

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
5-SEC, 12-FT INCIDENT WAVE FROM NORTH
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP, GAGE LOCATION
7-SEC, 8-FT INCIDENT WAVE FROM NORTH
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

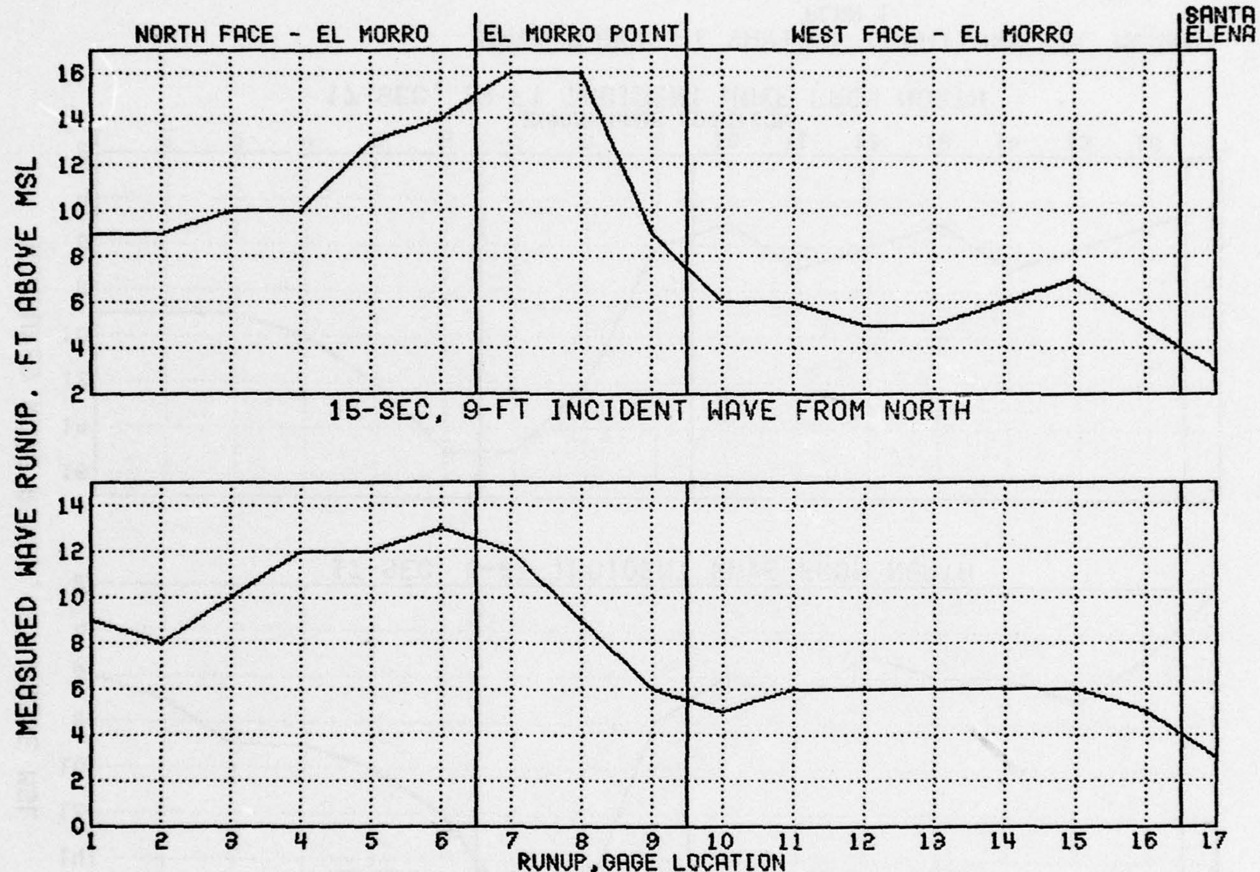

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
7-SEC, 16-FT INCIDENT WAVE FROM NORTH
RUNUP, GAGE LOCATION
9-SEC, 8-FT INCIDENT WAVE FROM NORTH
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
9-SEC, 16-FT INCIDENT WAVE FROM NORTH
9-SEC, 22-FT INCIDENT WAVE FROM NORTH
RUNUP GAGE LOCATION
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

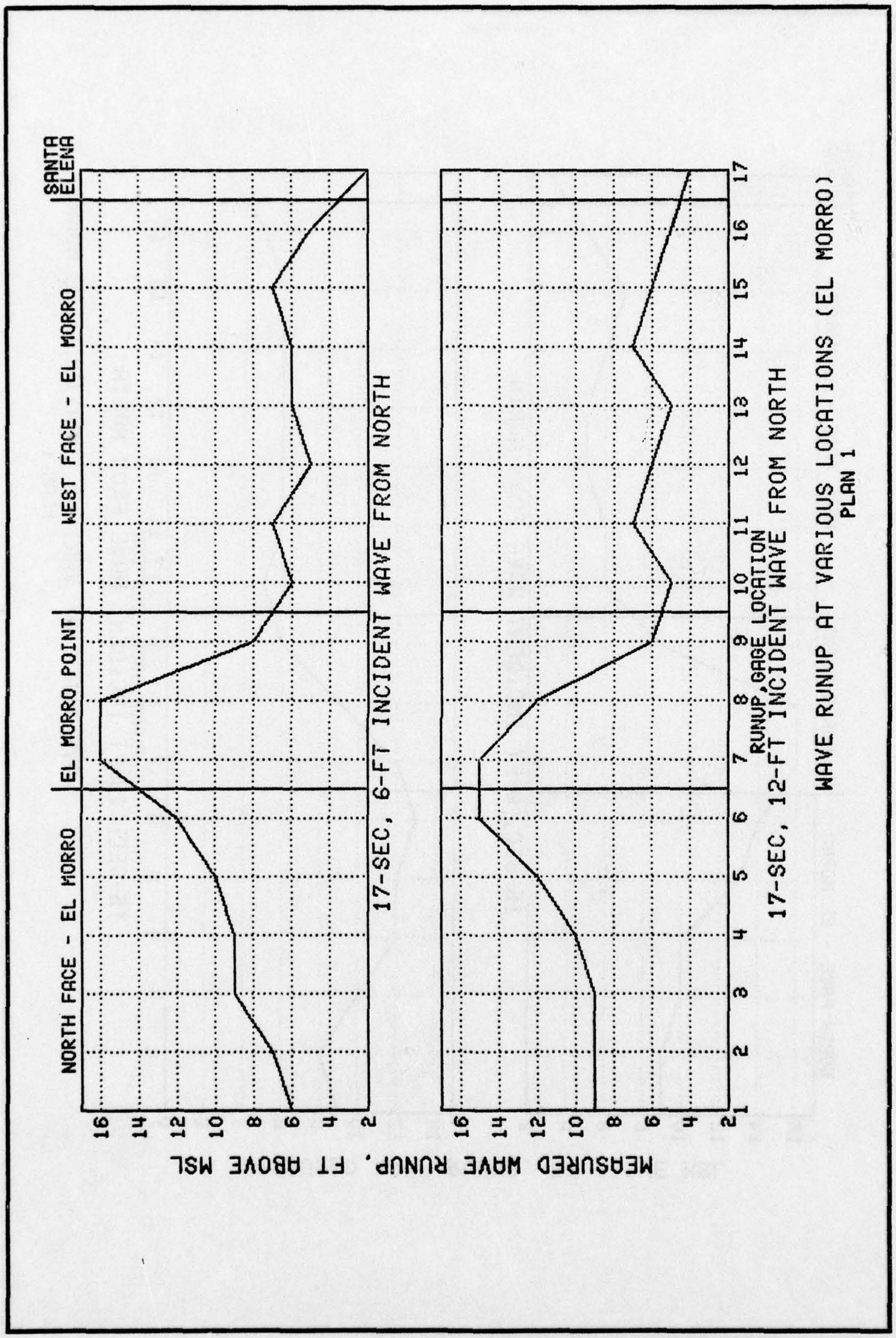


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

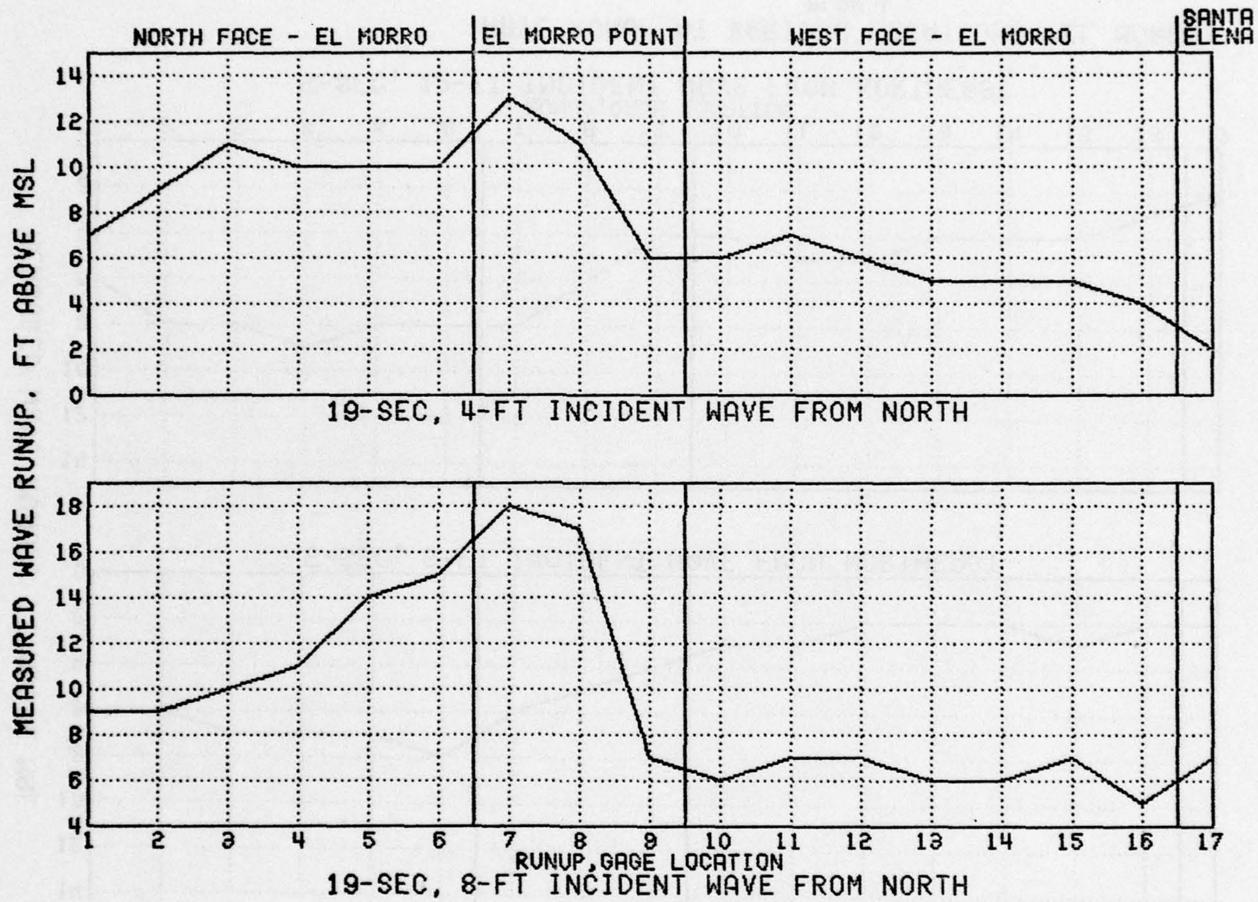

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
13-SEC, 9-FT INCIDENT WAVE FROM NORTH
13-SEC, 18-FT INCIDENT WAVE FROM NORTH
RUNUP GAGE LOCATION
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
16 14 12 10 8 6 4 2
14 12 10 8 6 4 2 0
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



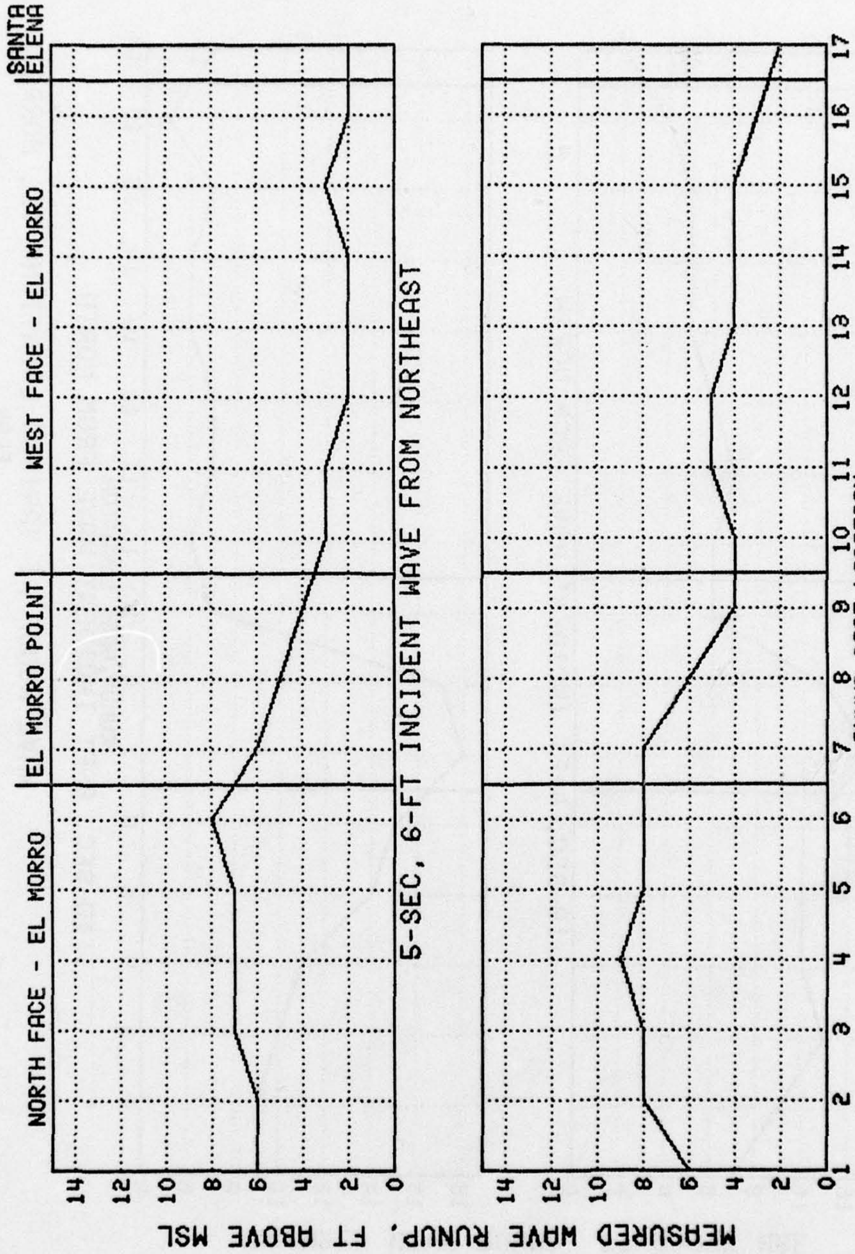
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



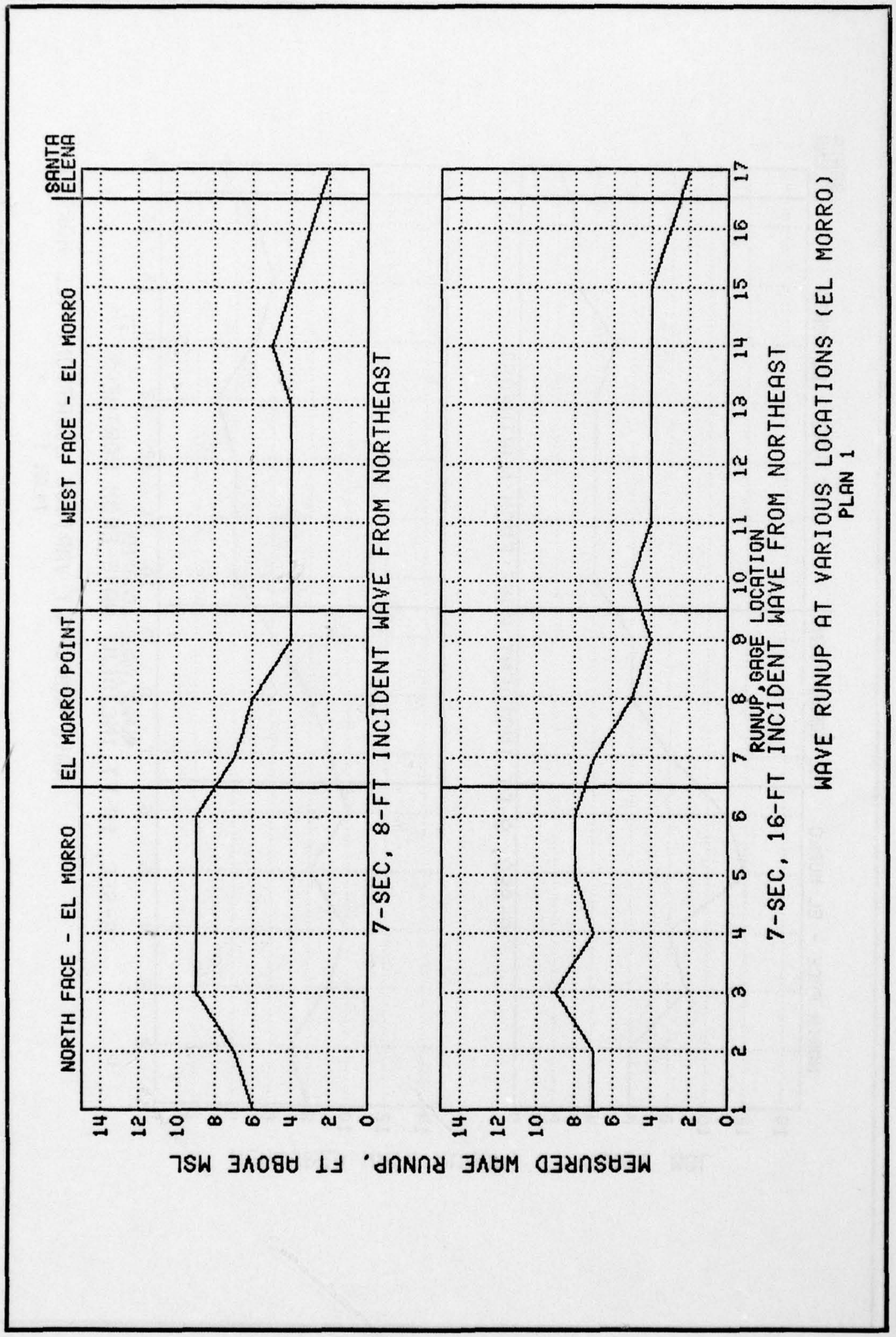
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



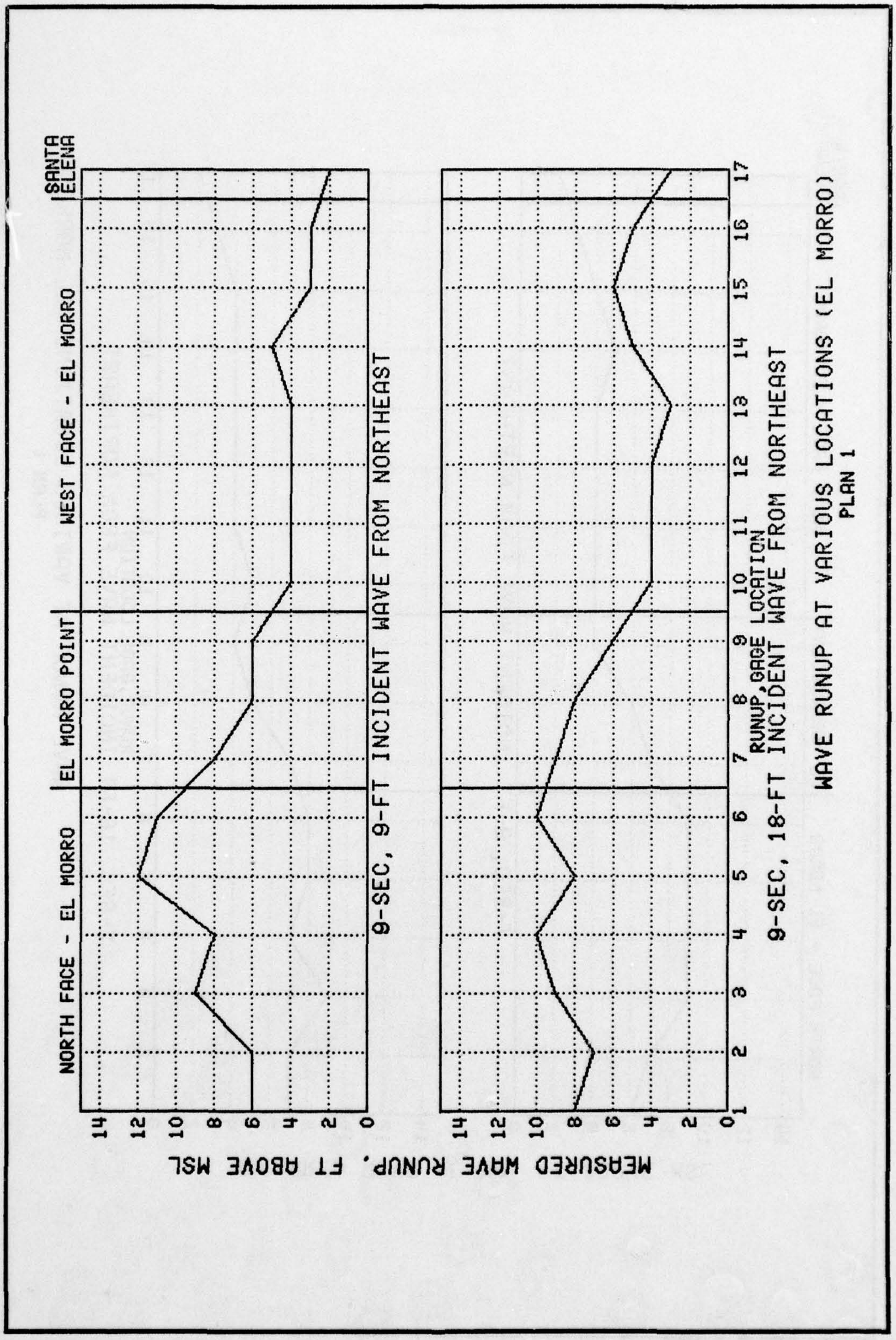
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

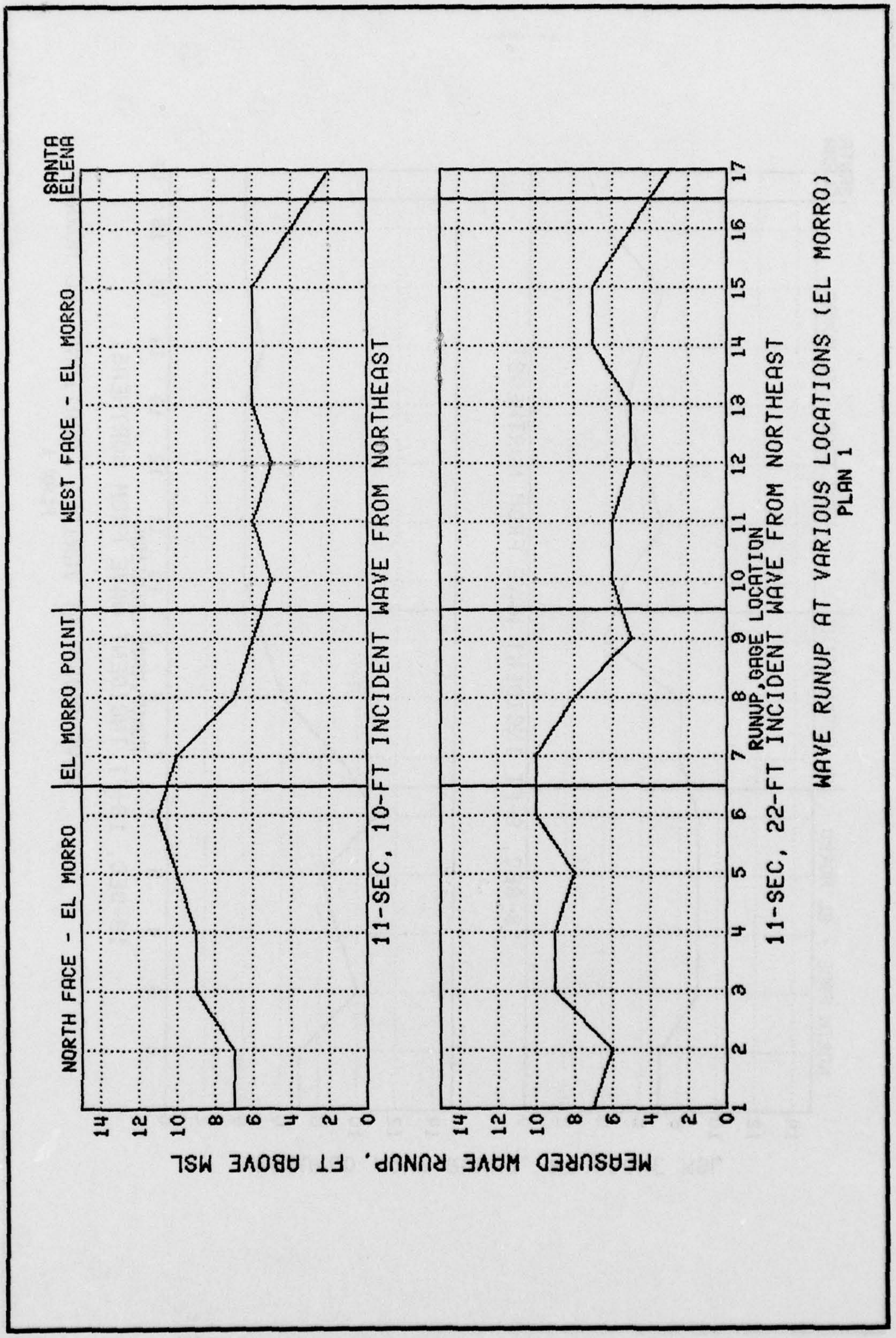


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

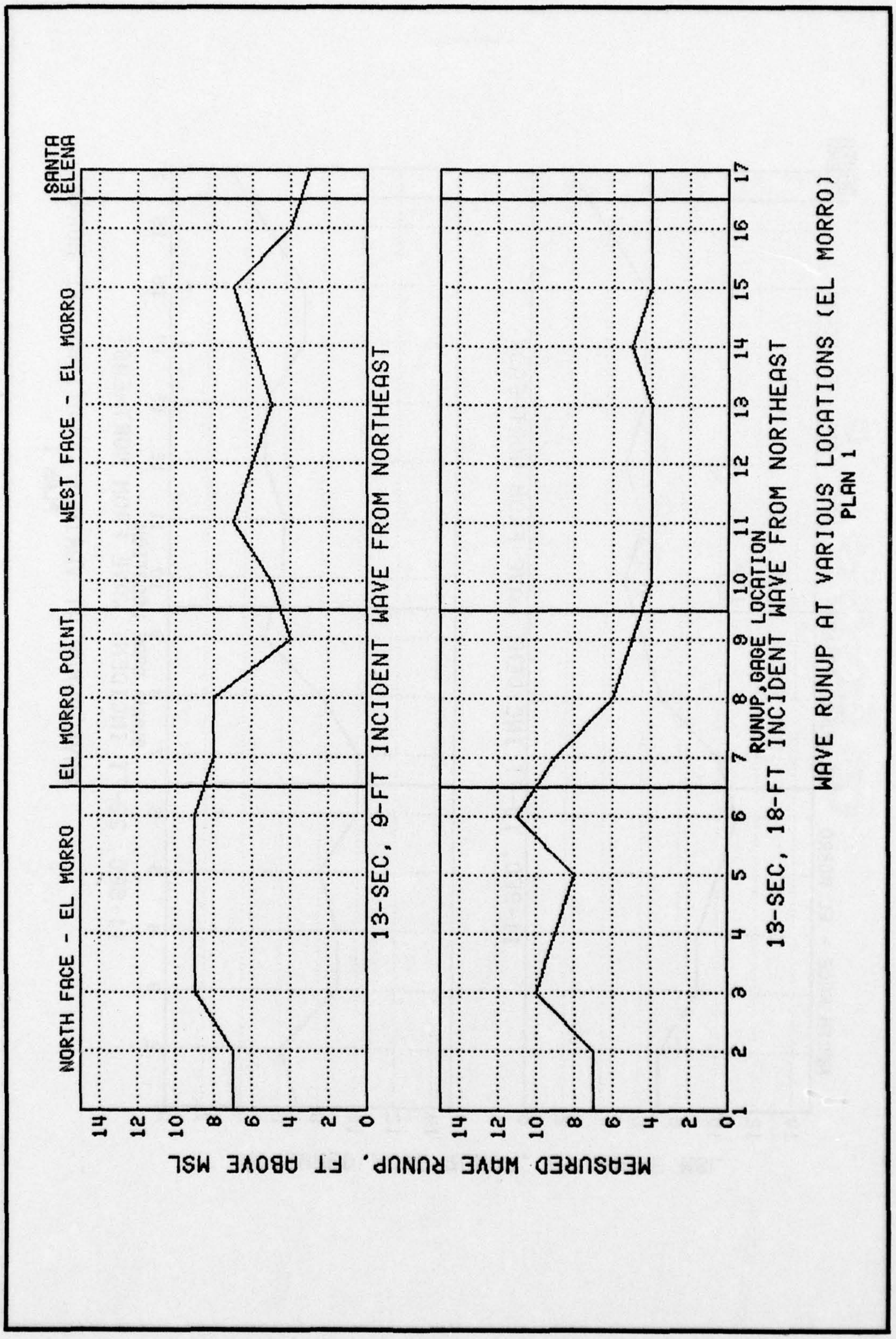


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
9-SEC, 9-FT INCIDENT WAVE FROM NORTHEAST
RUNUP,GAGE LOCATION
9-SEC, 18-FT INCIDENT WAVE FROM NORTHEAST
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

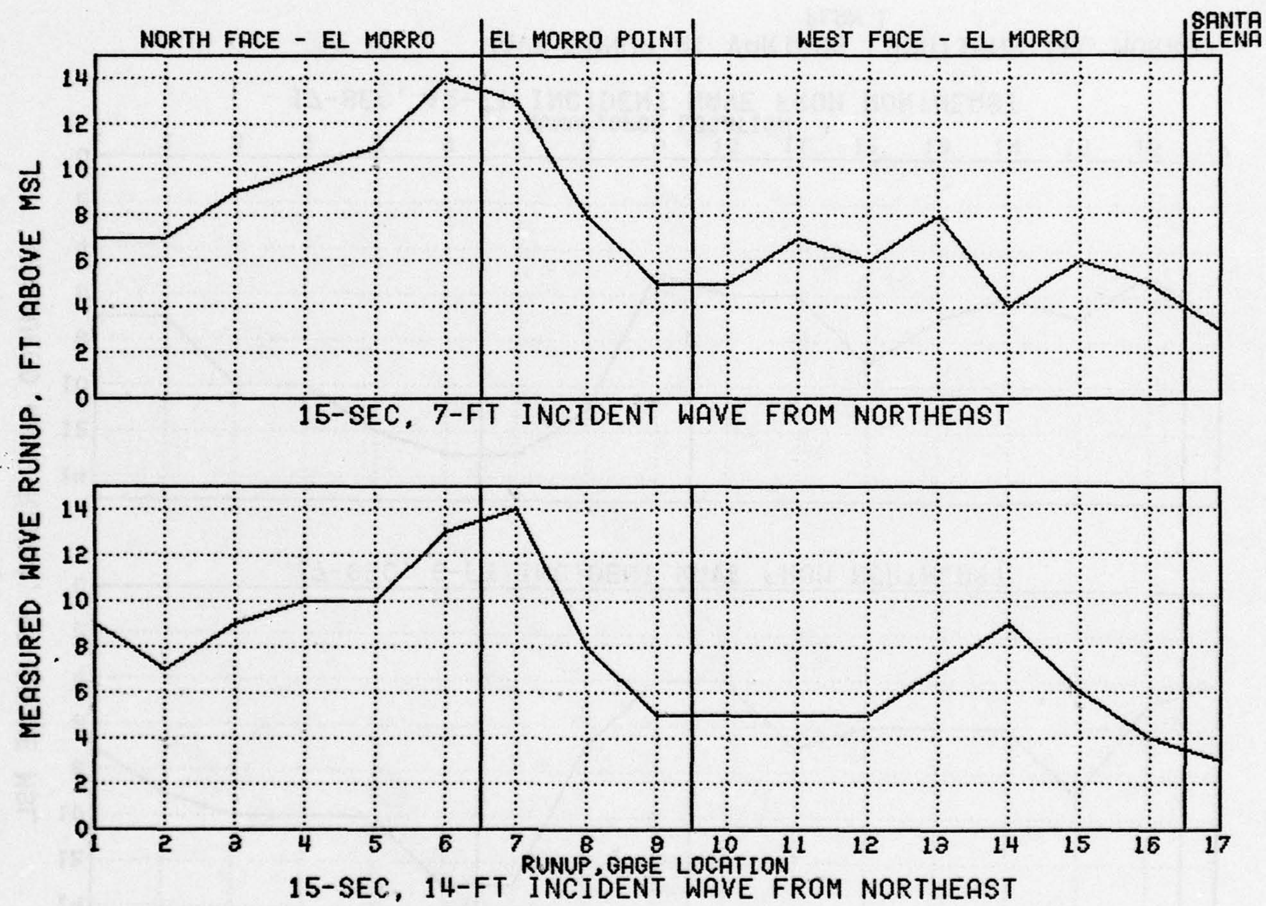


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

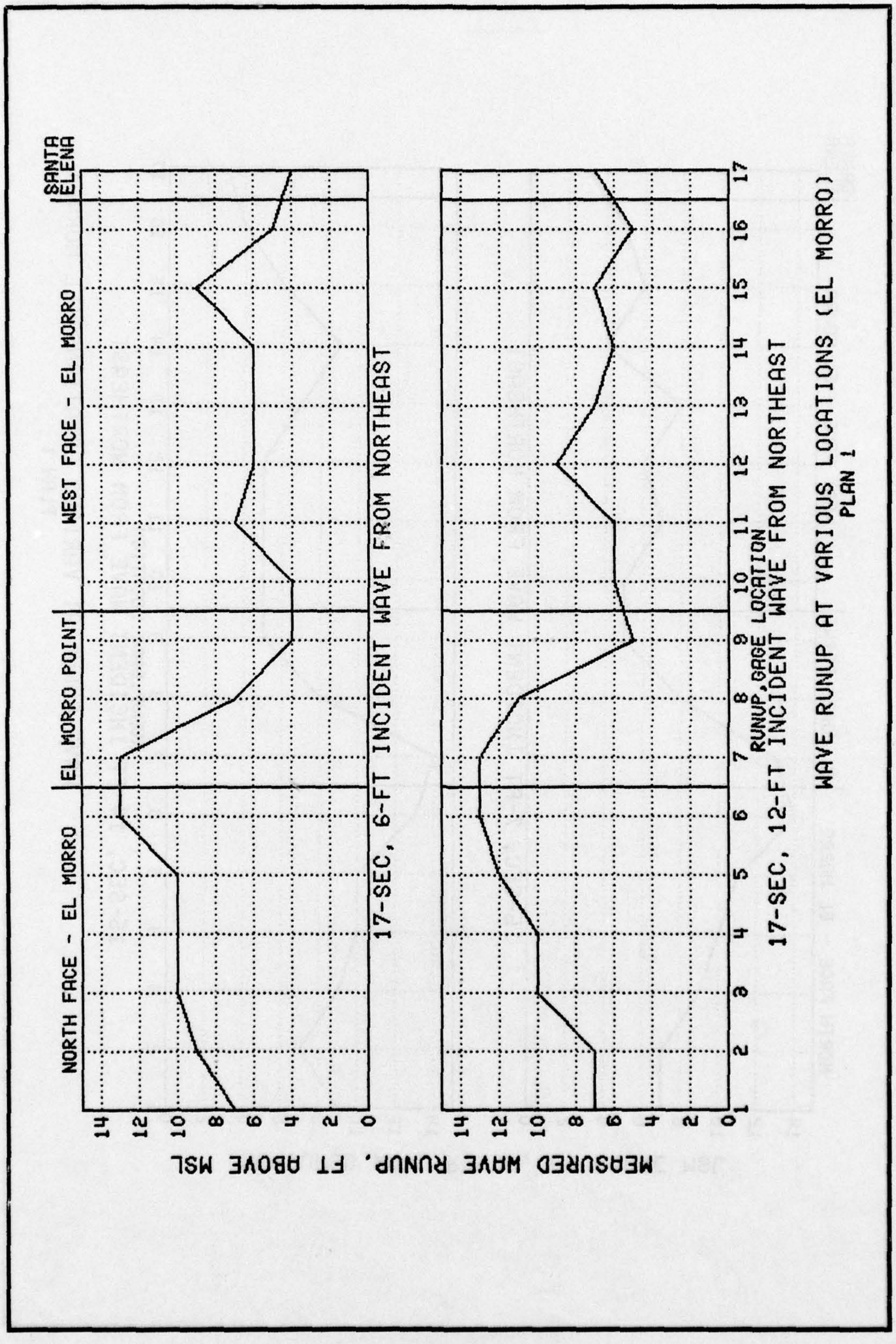


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1

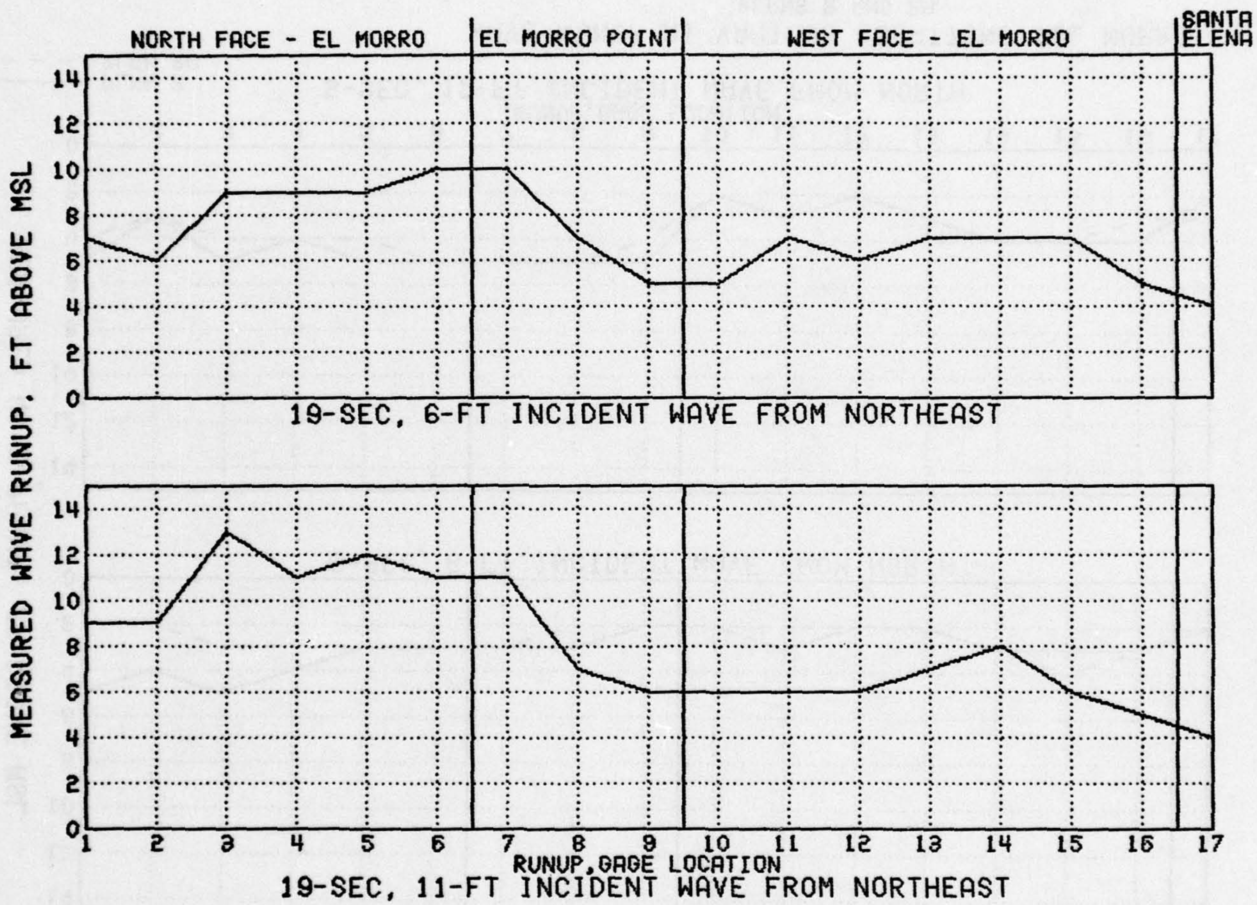
PLATE 76



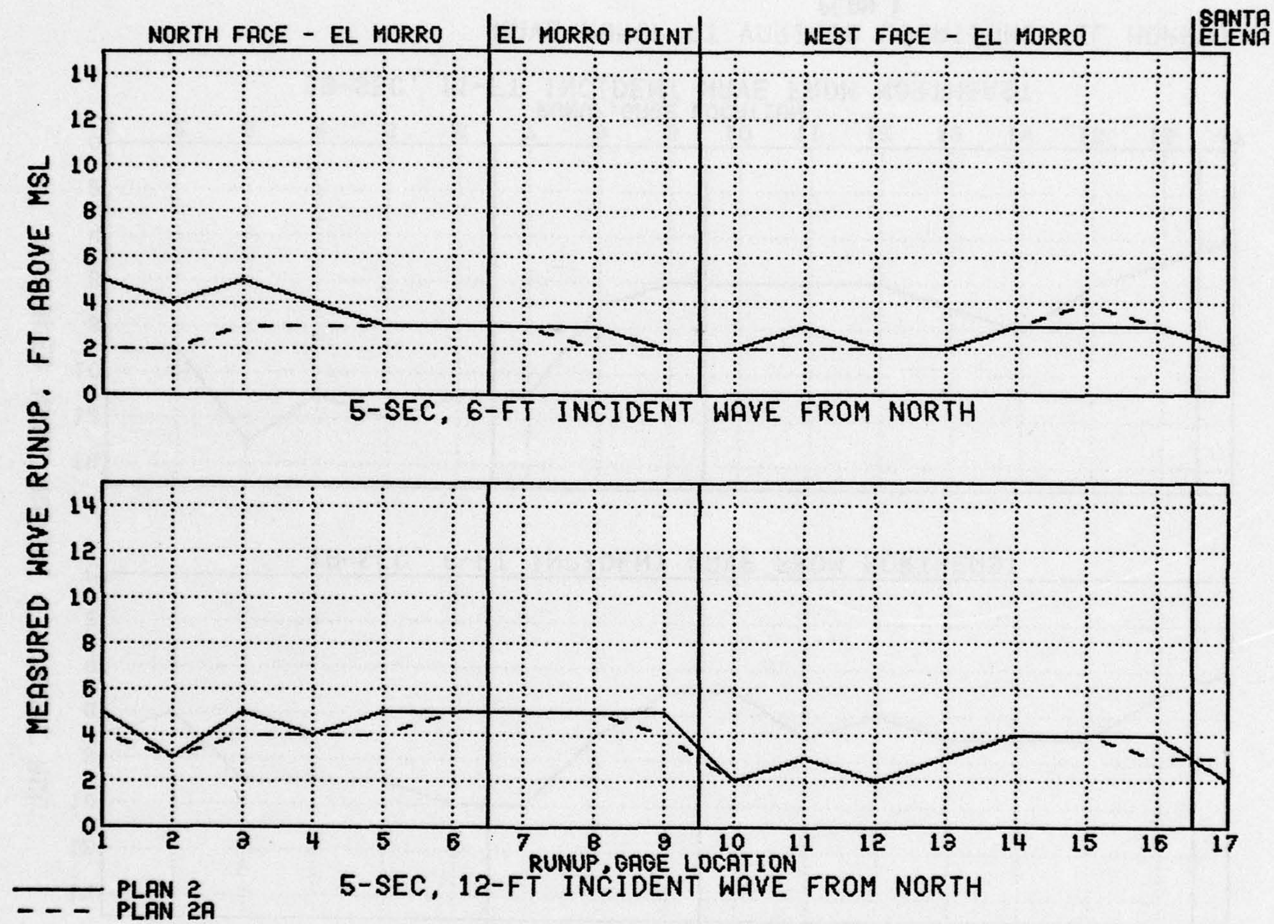
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



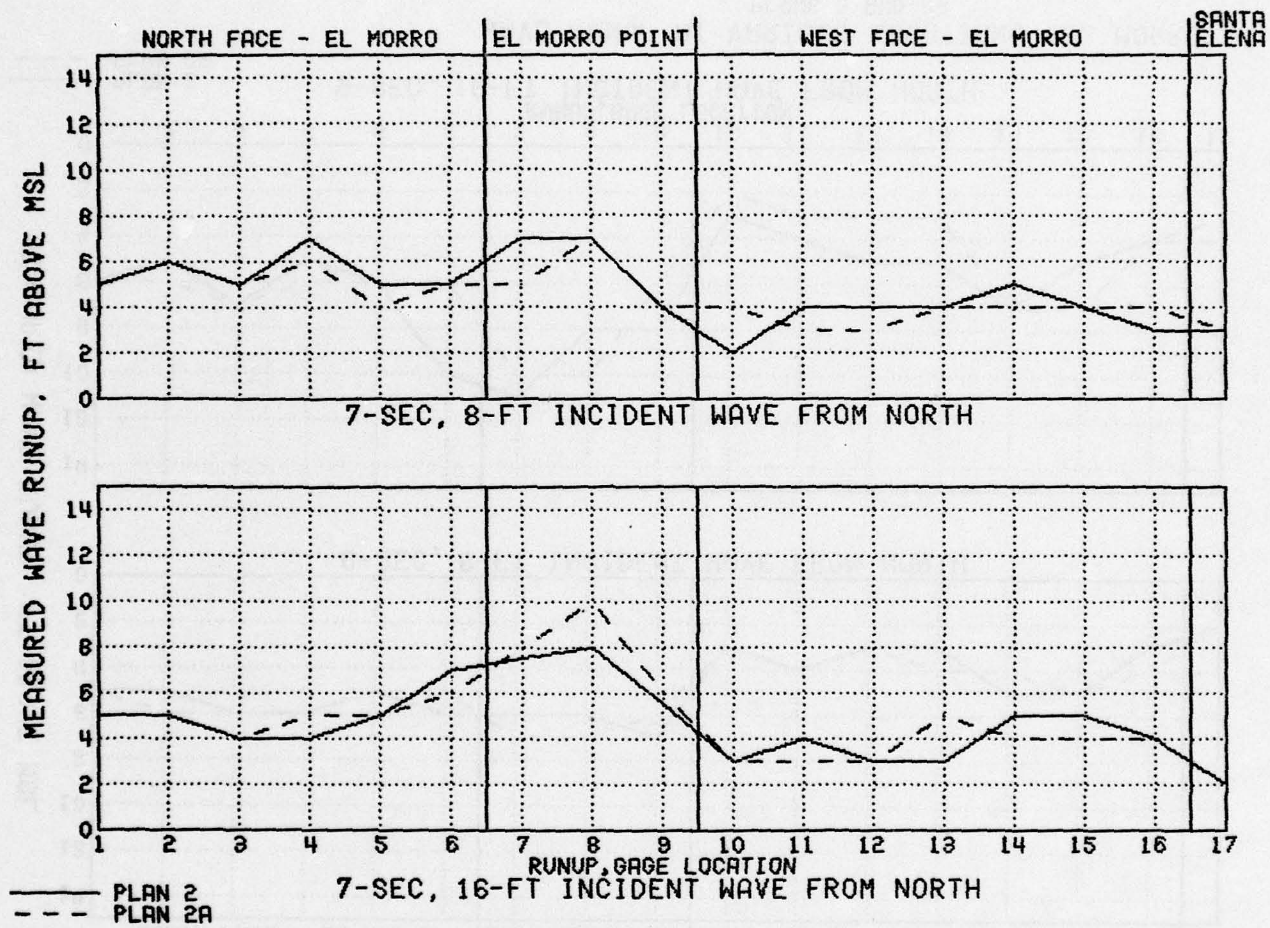
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



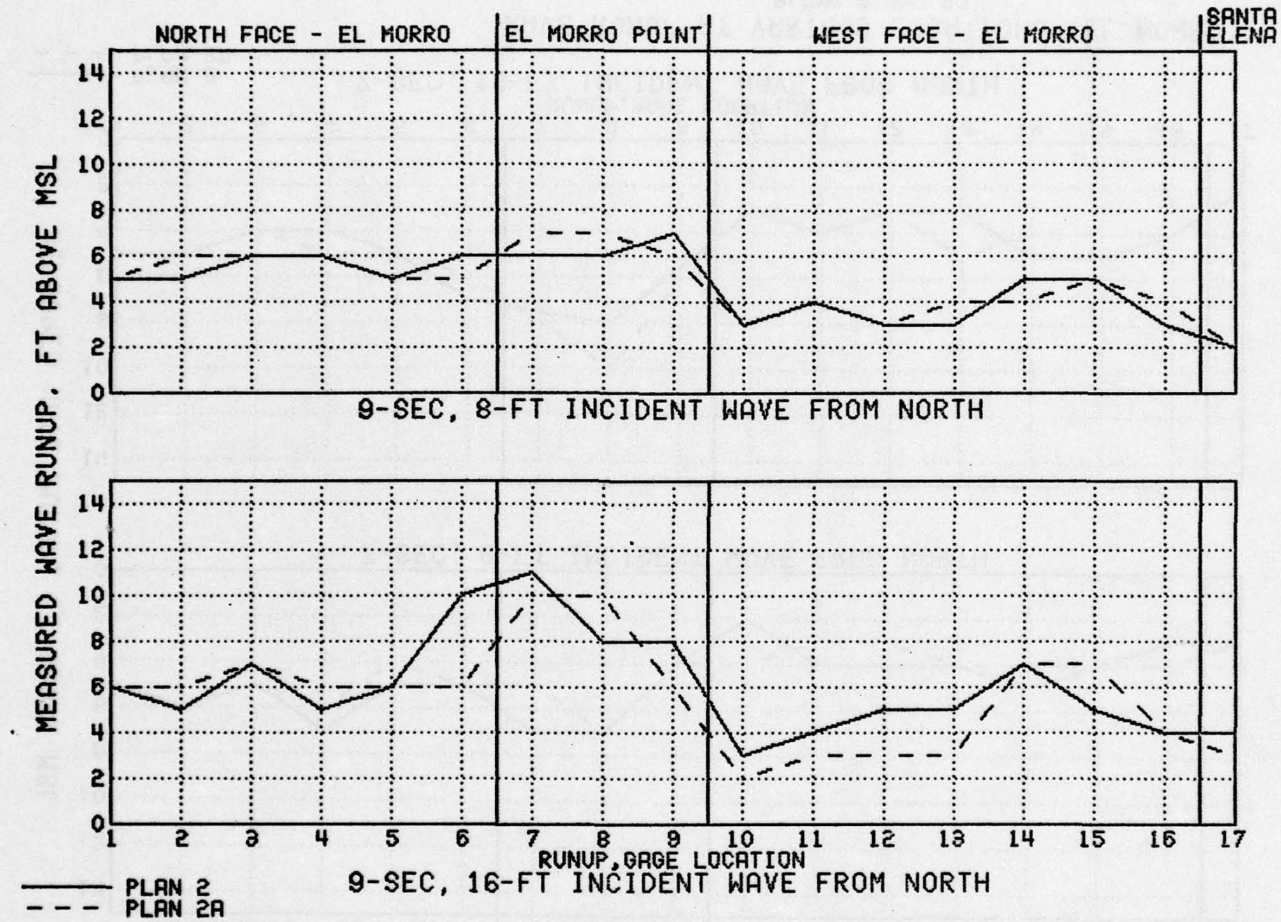
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 1



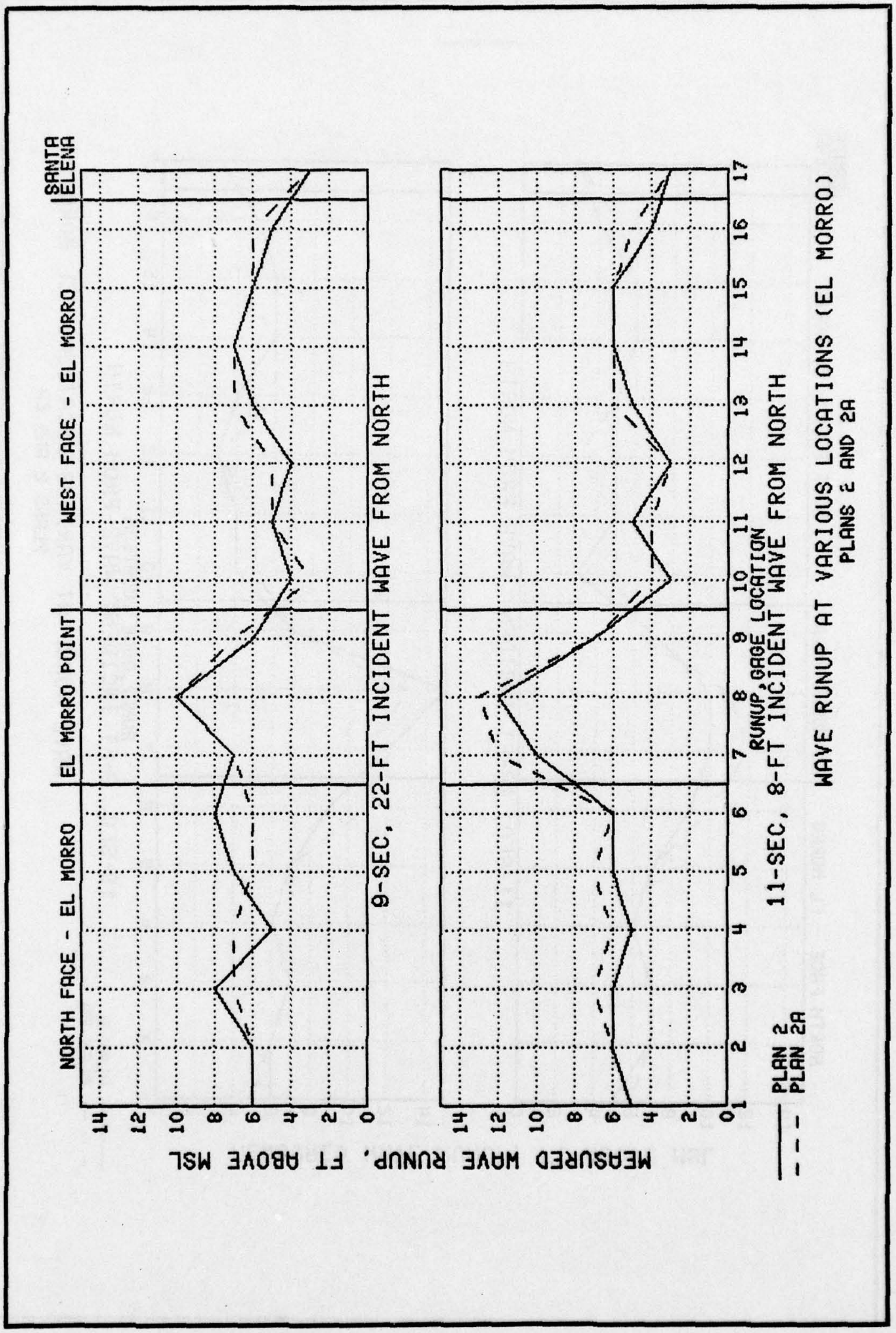
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



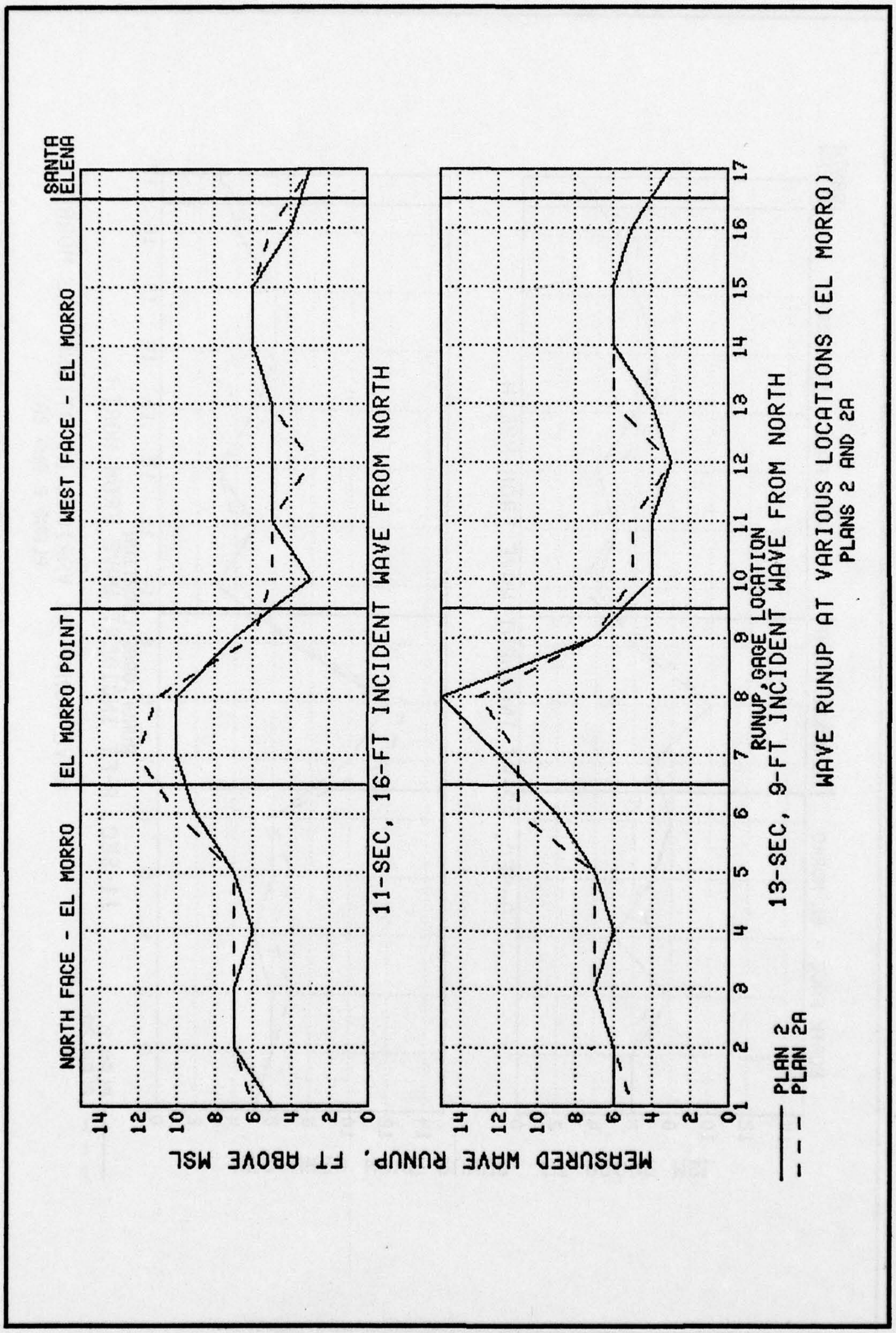
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



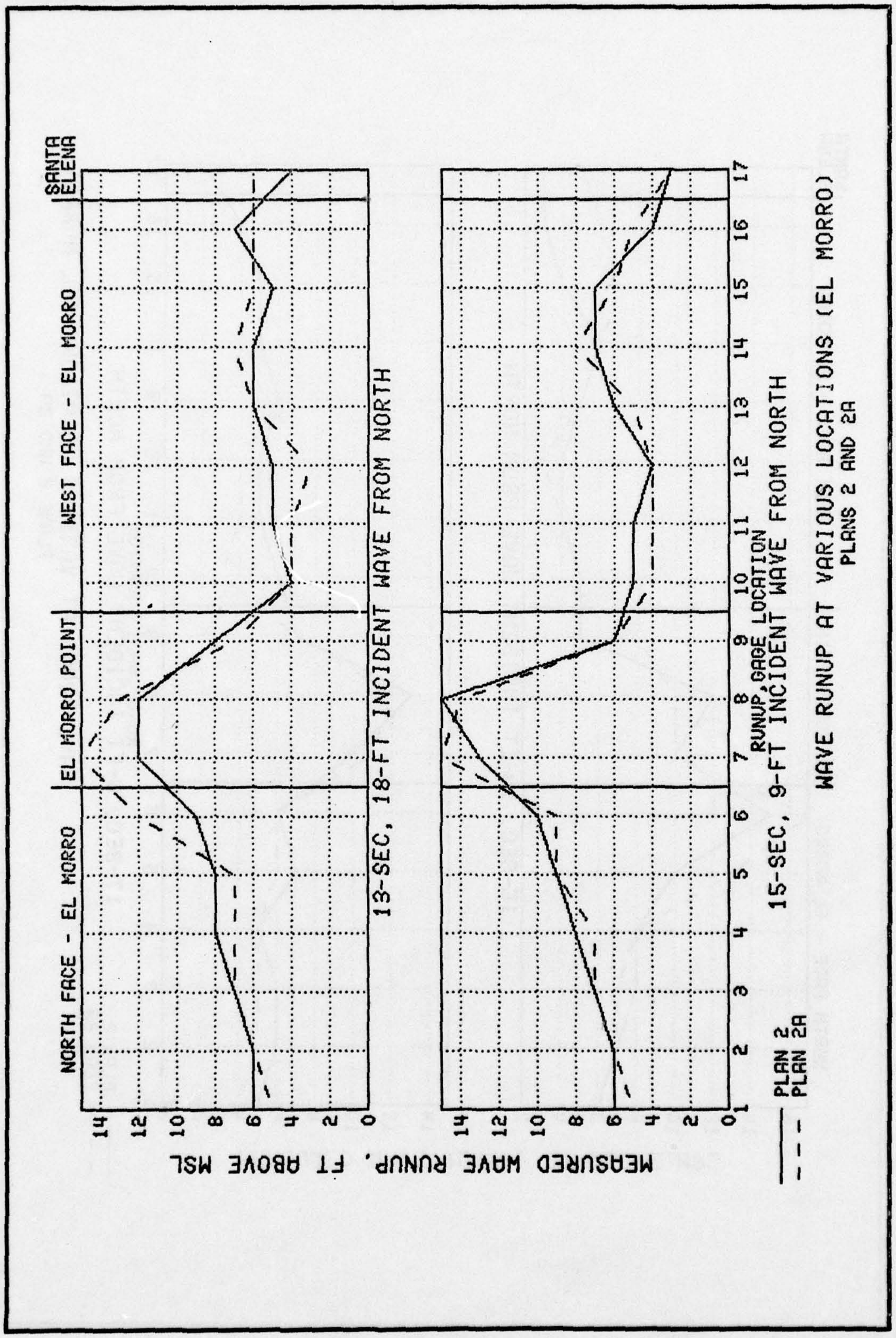
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



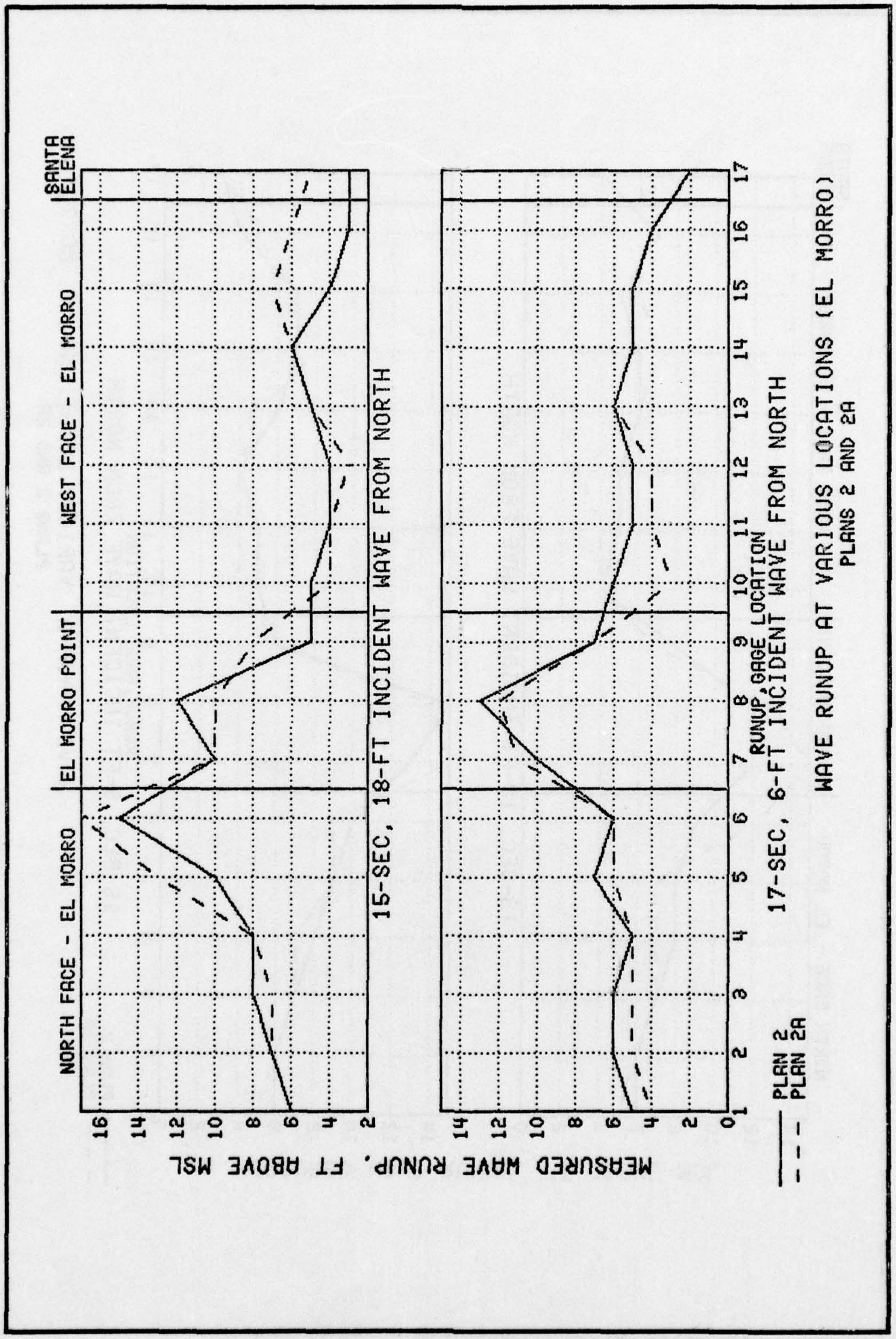
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
9-SEC, 22-FT INCIDENT WAVE FROM NORTH
11-SEC, 8-FT INCIDENT WAVE FROM NORTH
RUNUP GAGE LOCATION
PLAN 2
PLAN 2A
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



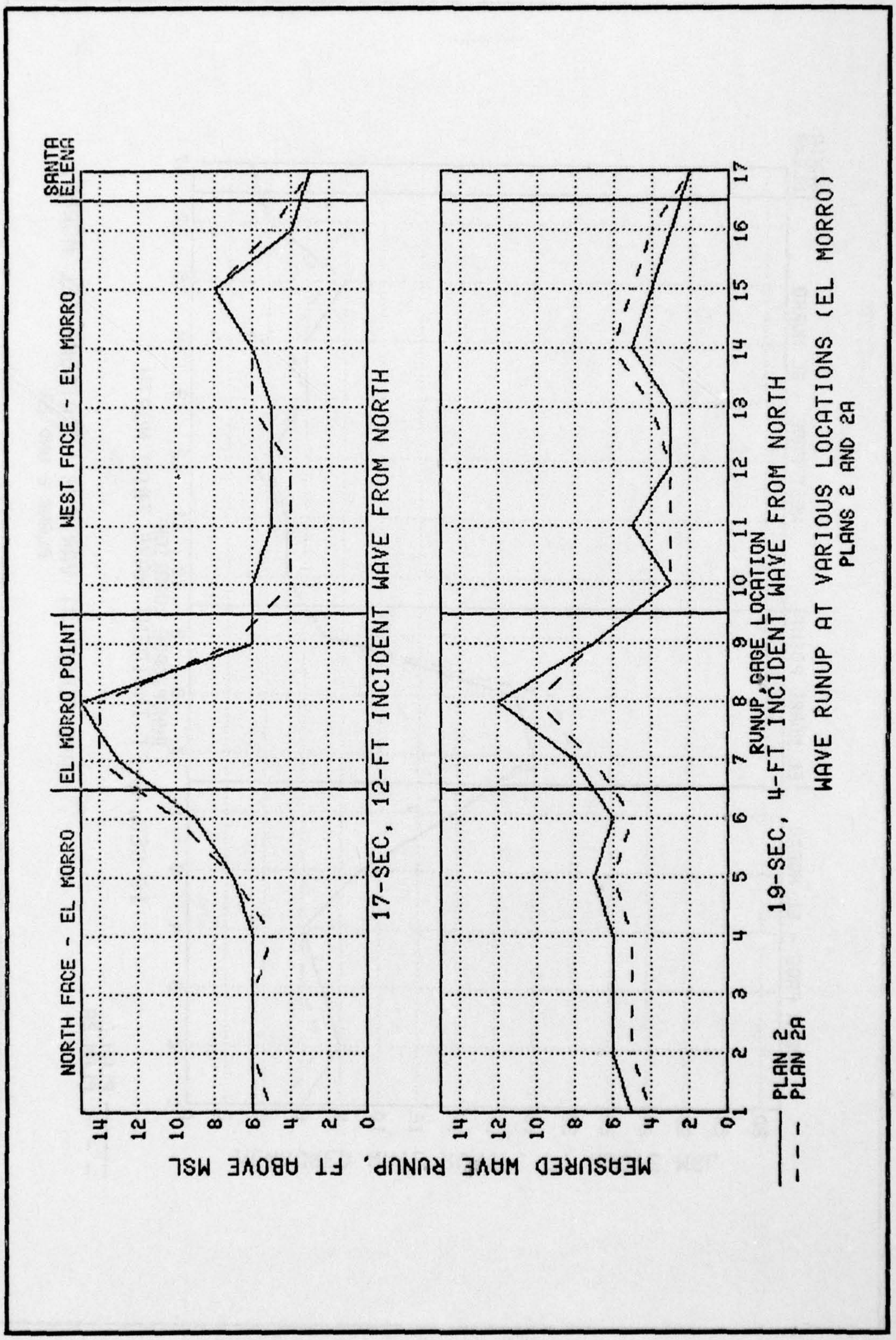
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



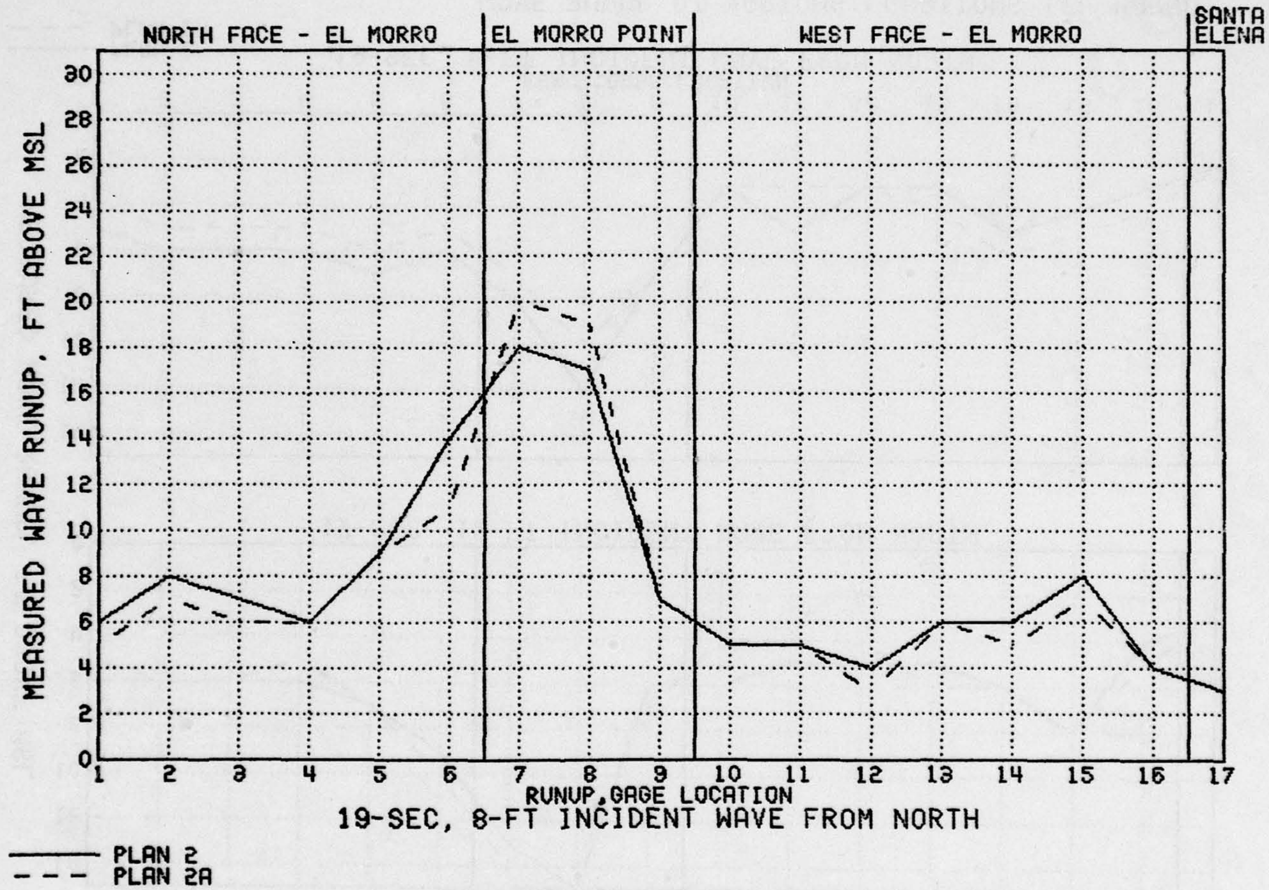
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



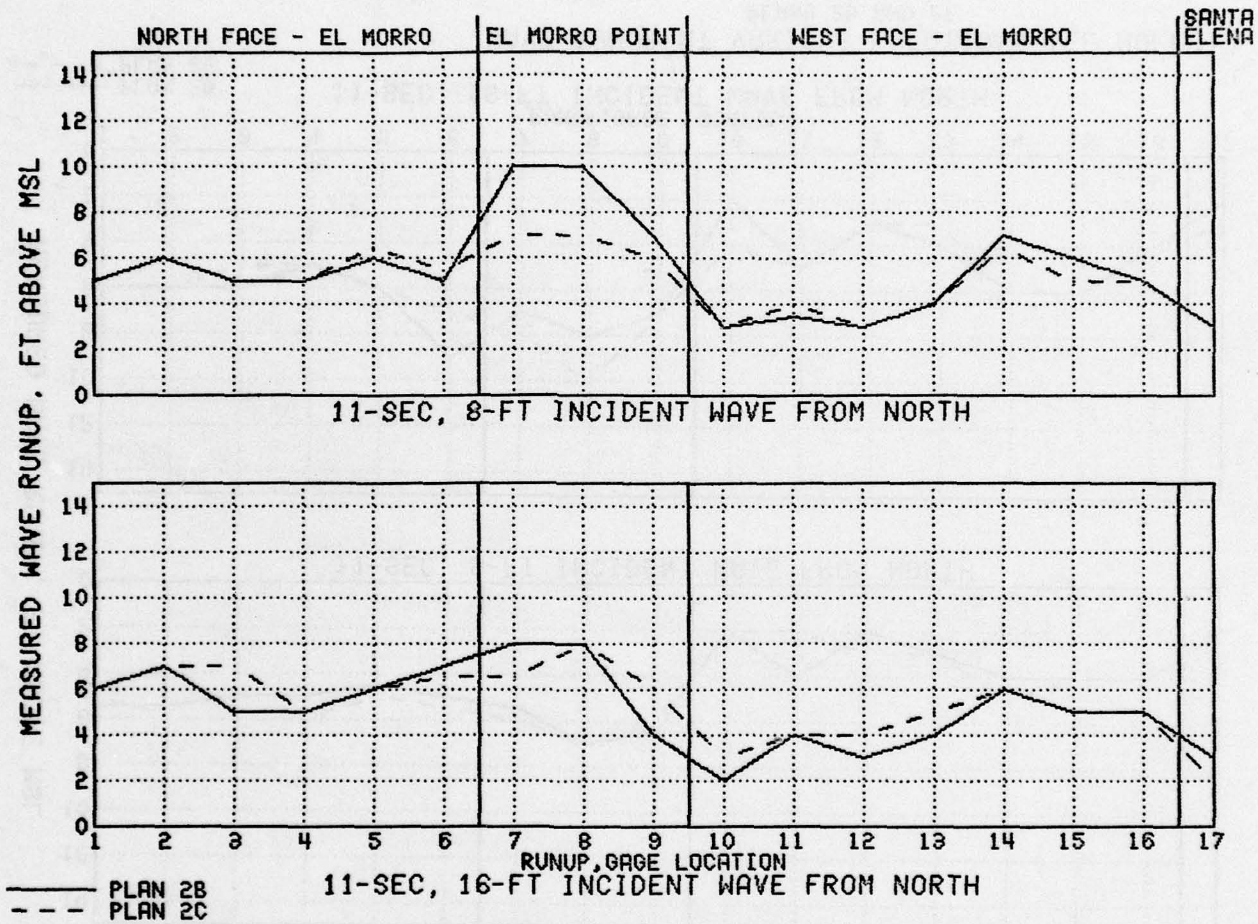
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



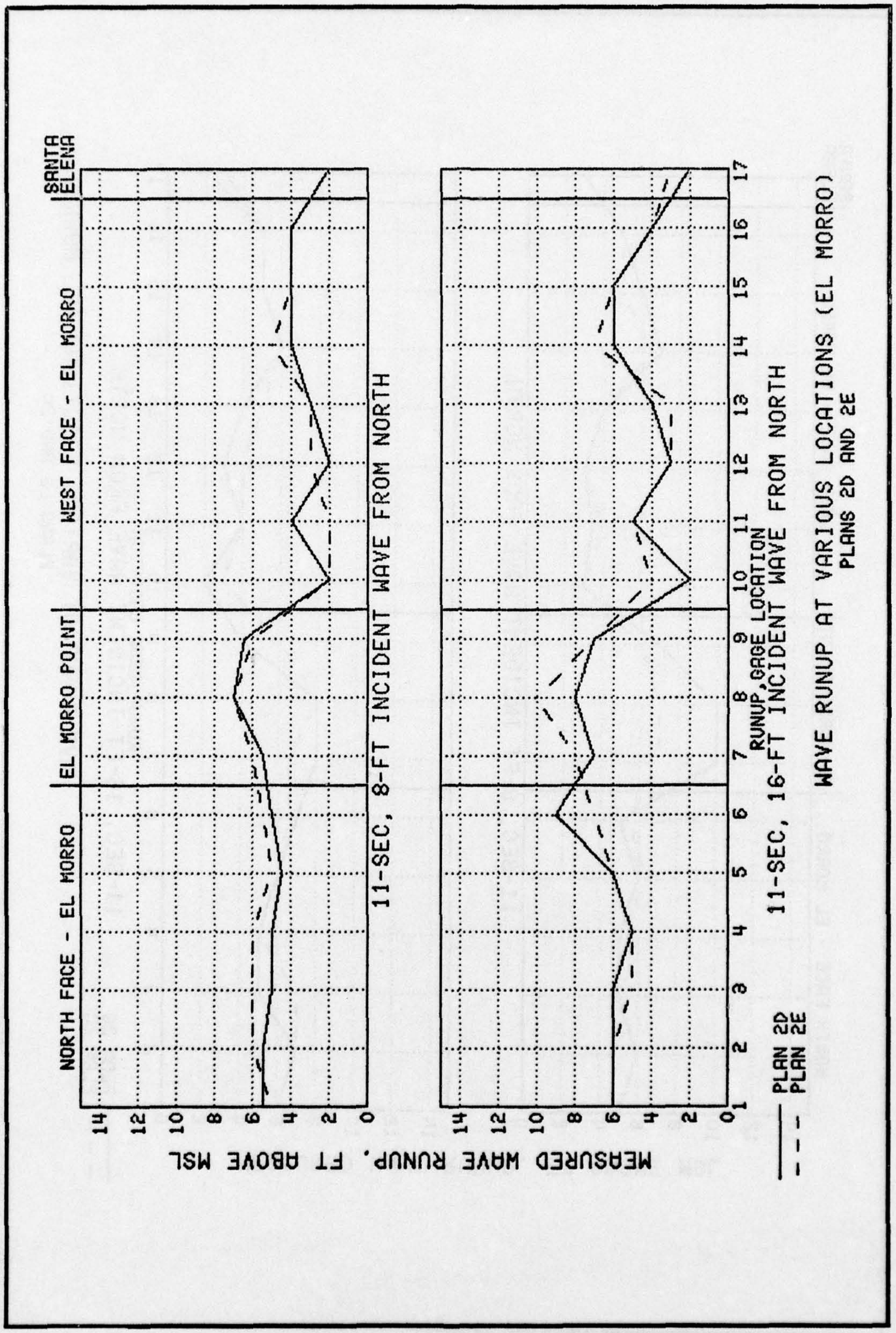
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



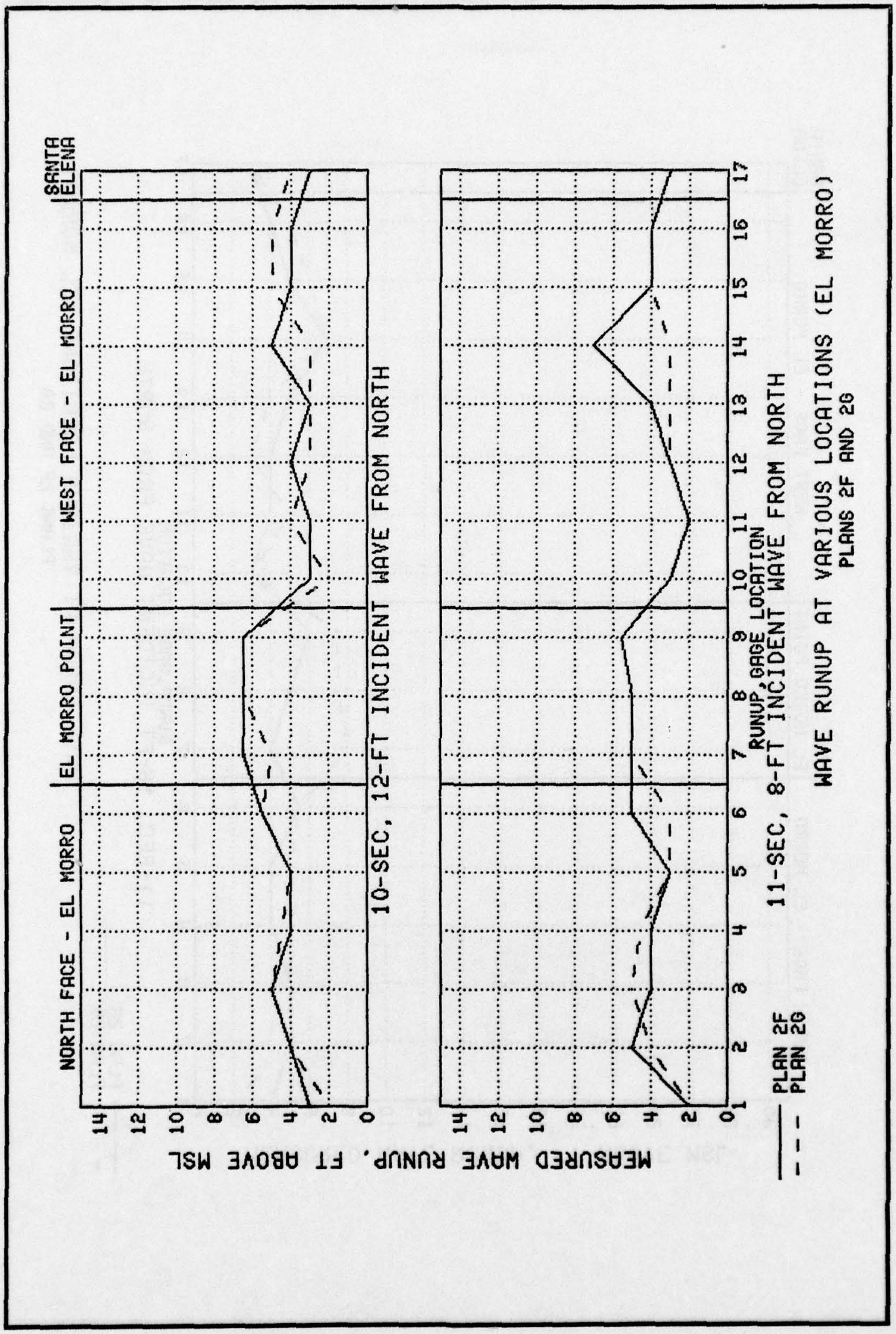
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2 AND 2A



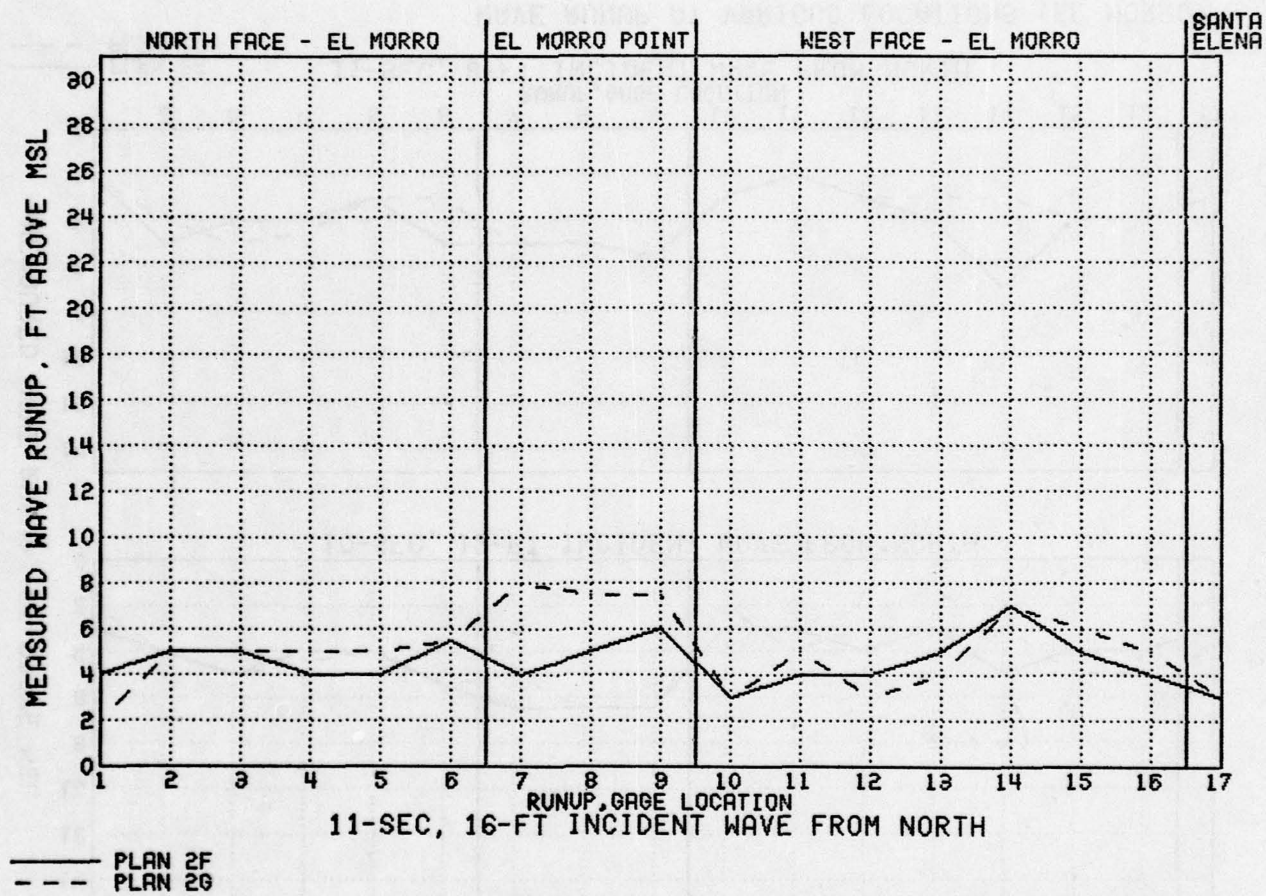
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2B AND 2C



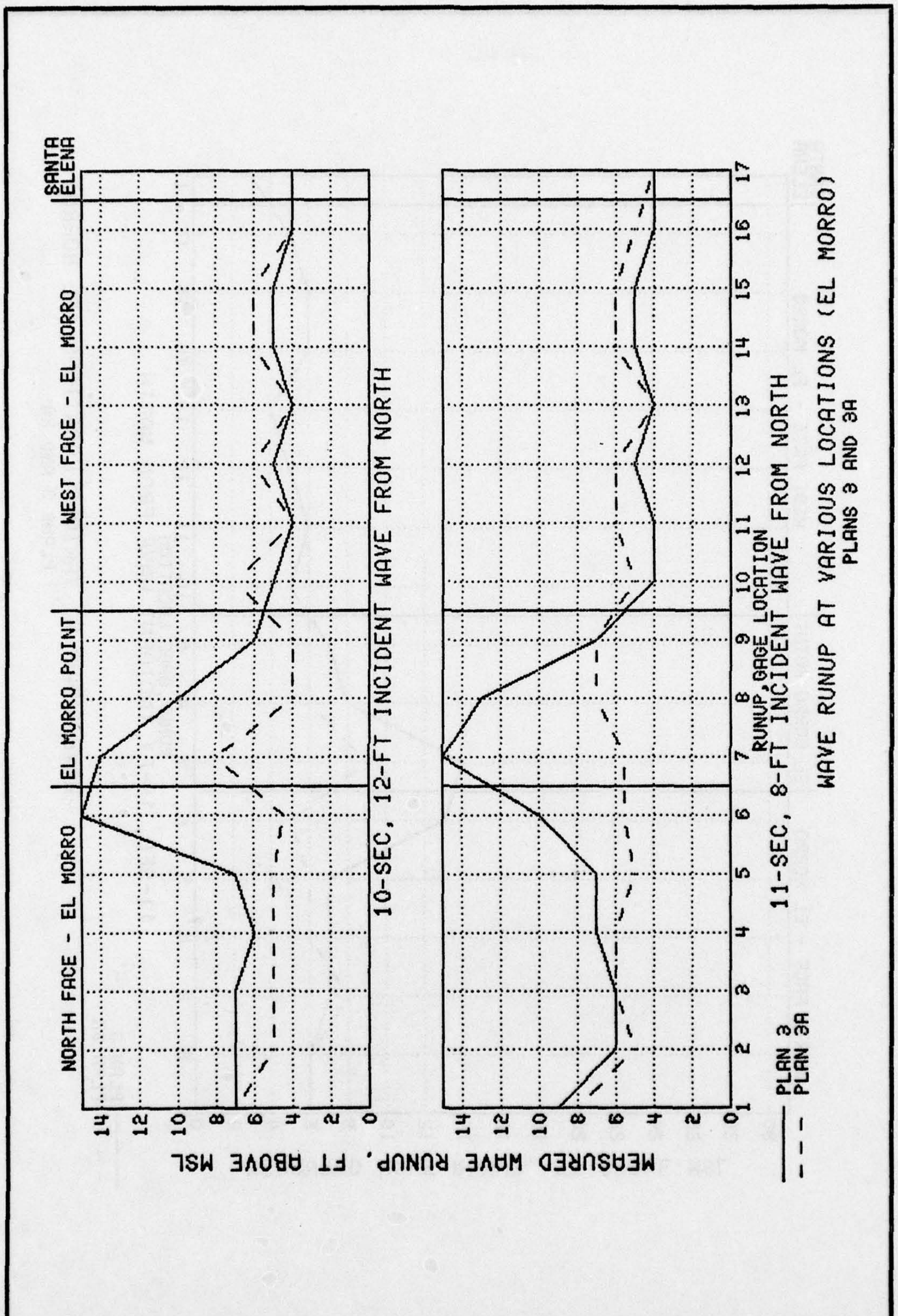
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2D AND 2E



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2F AND 2G

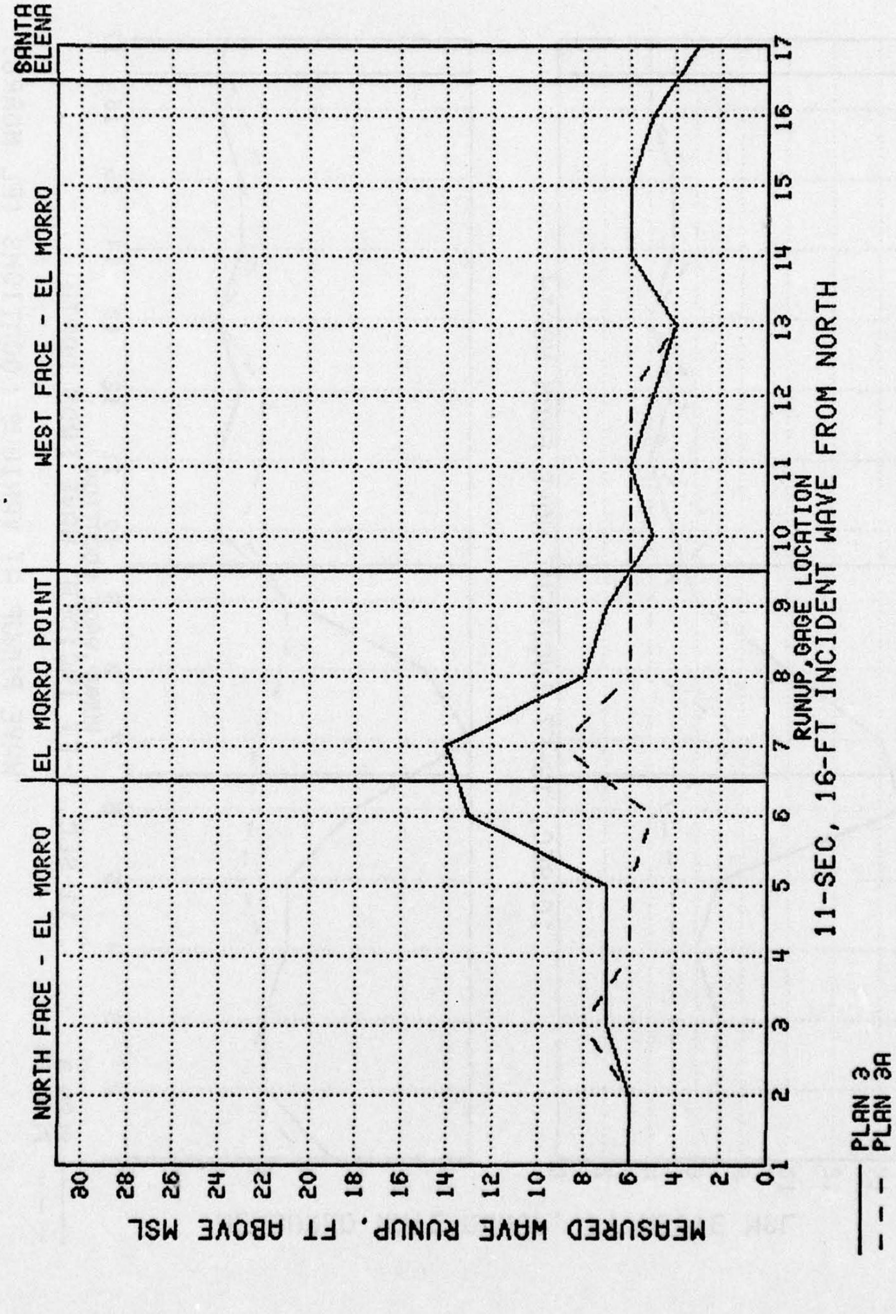


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 2F AND 2G

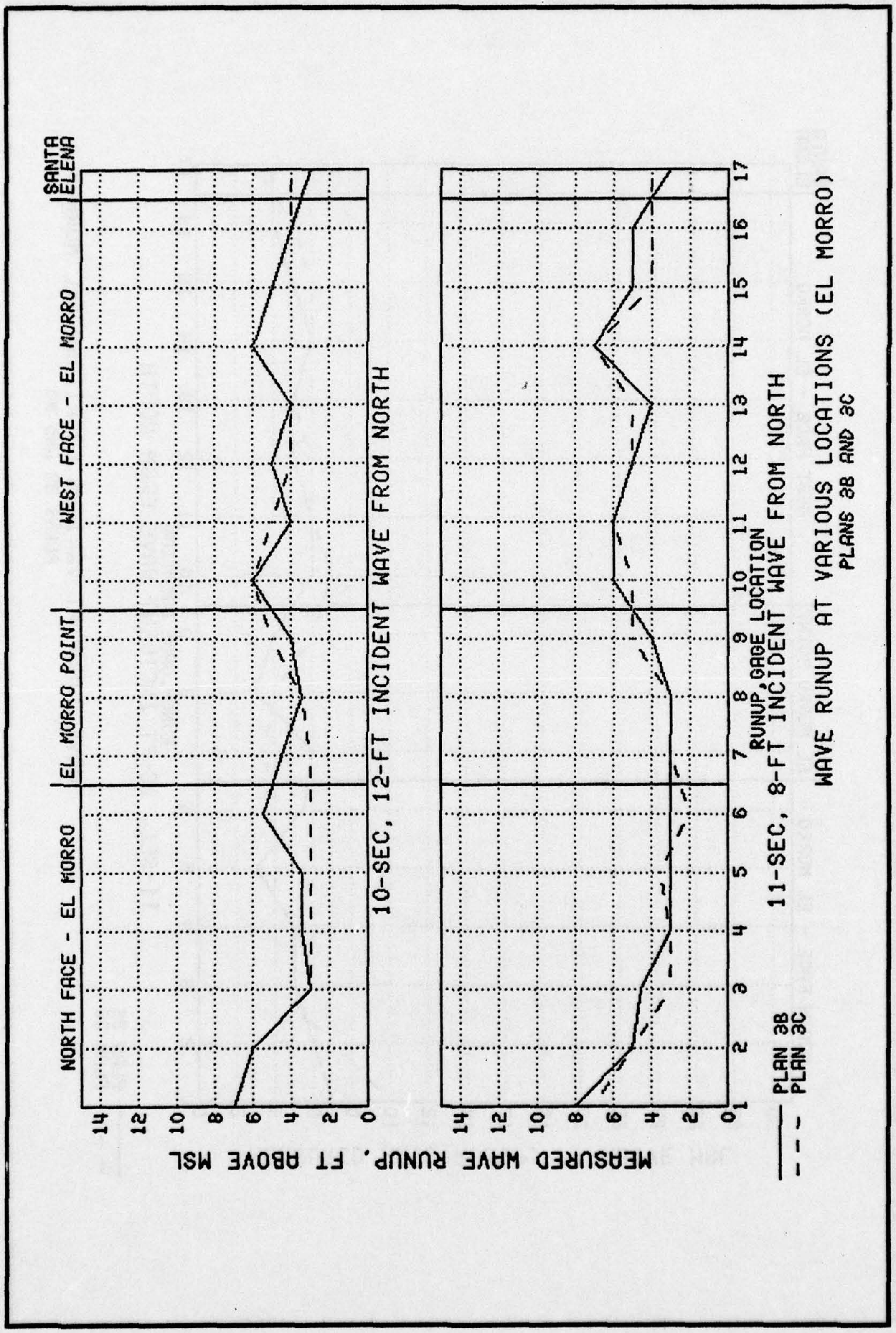


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 3 AND 3A

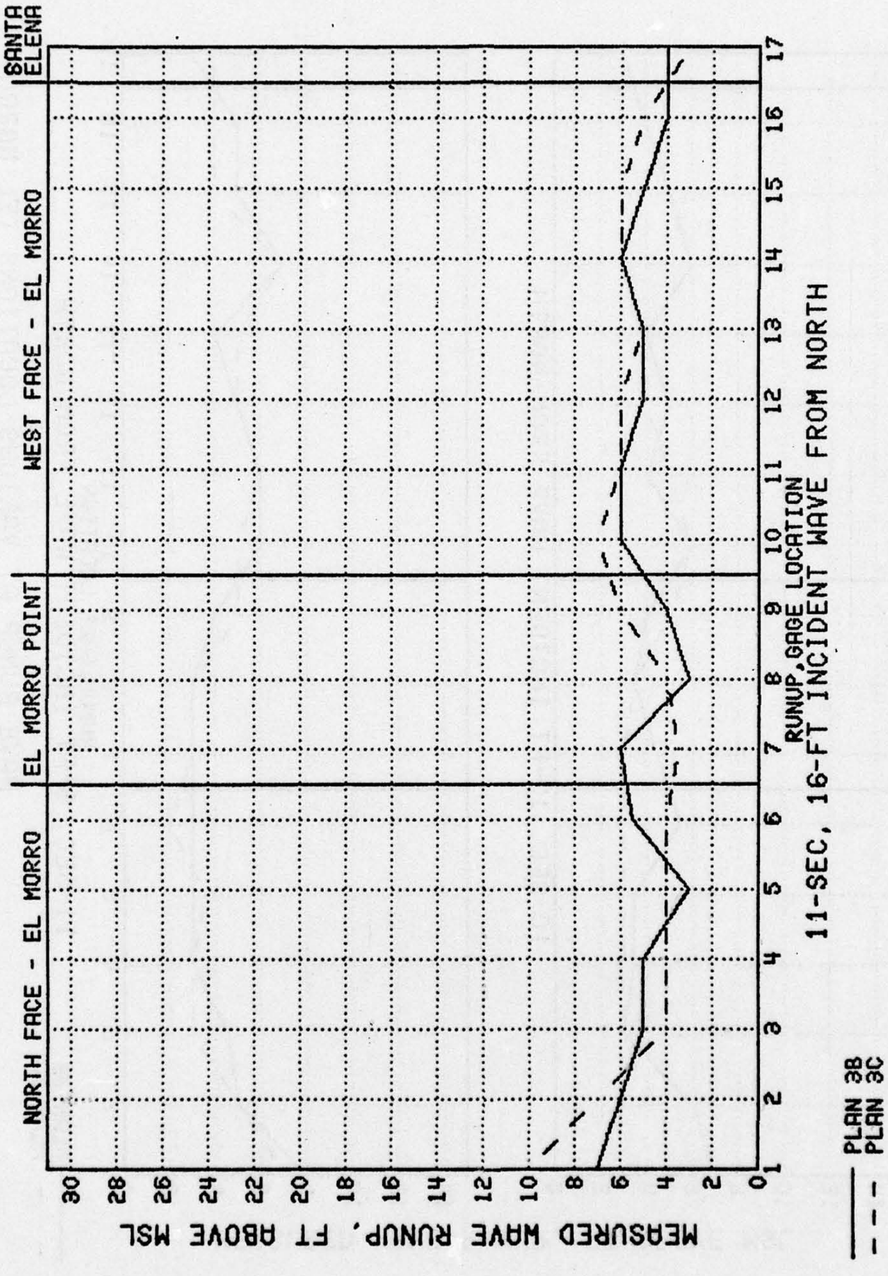
PLATE 93



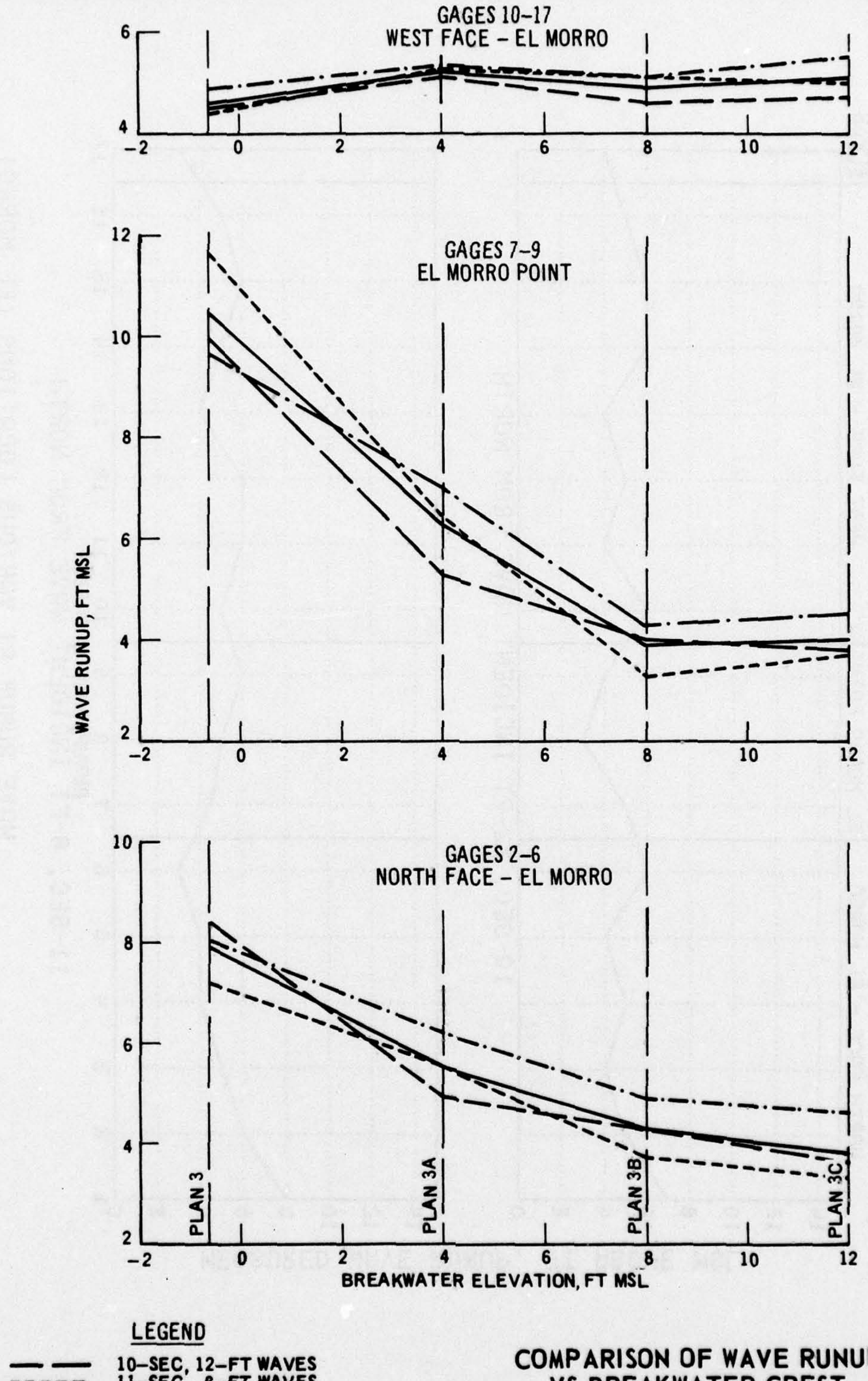
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 3 AND 3A



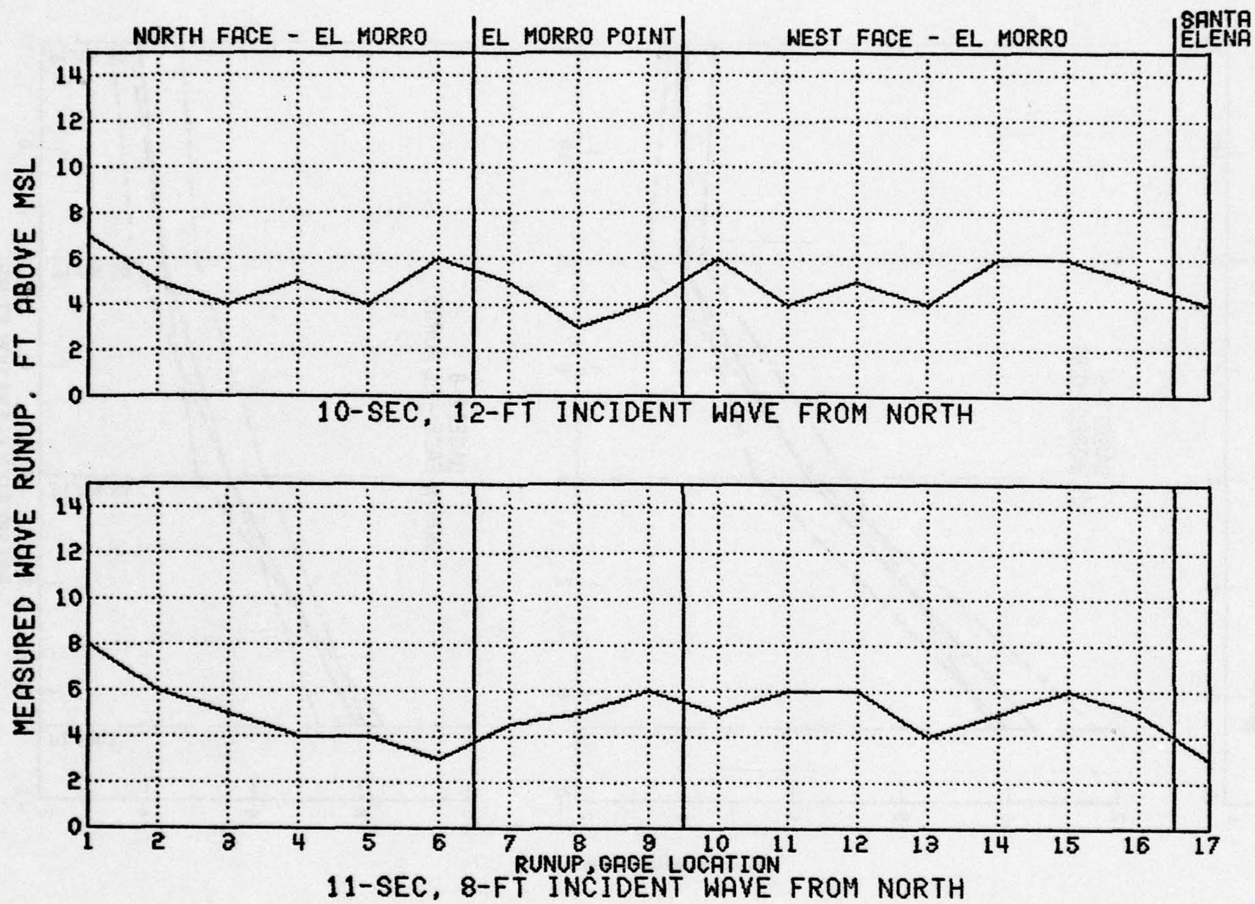
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 3B AND 3C



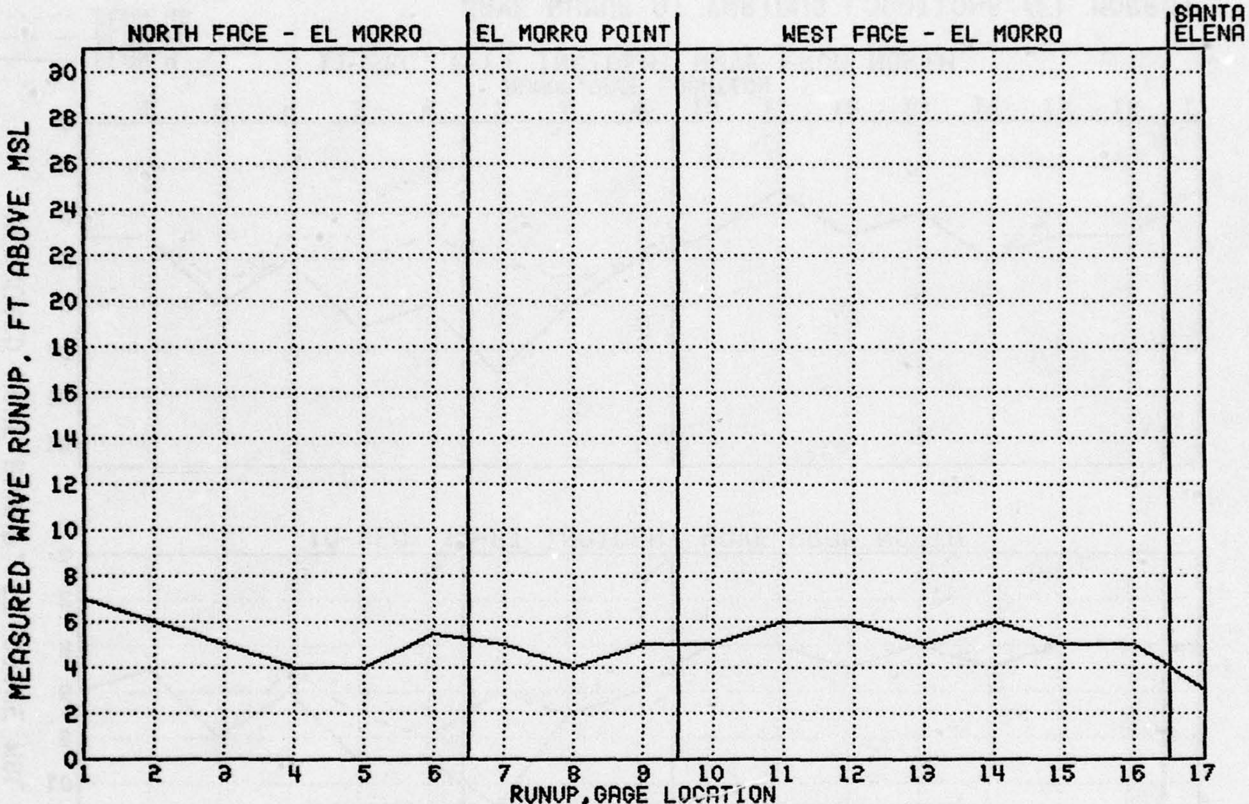
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 3B AND 3C



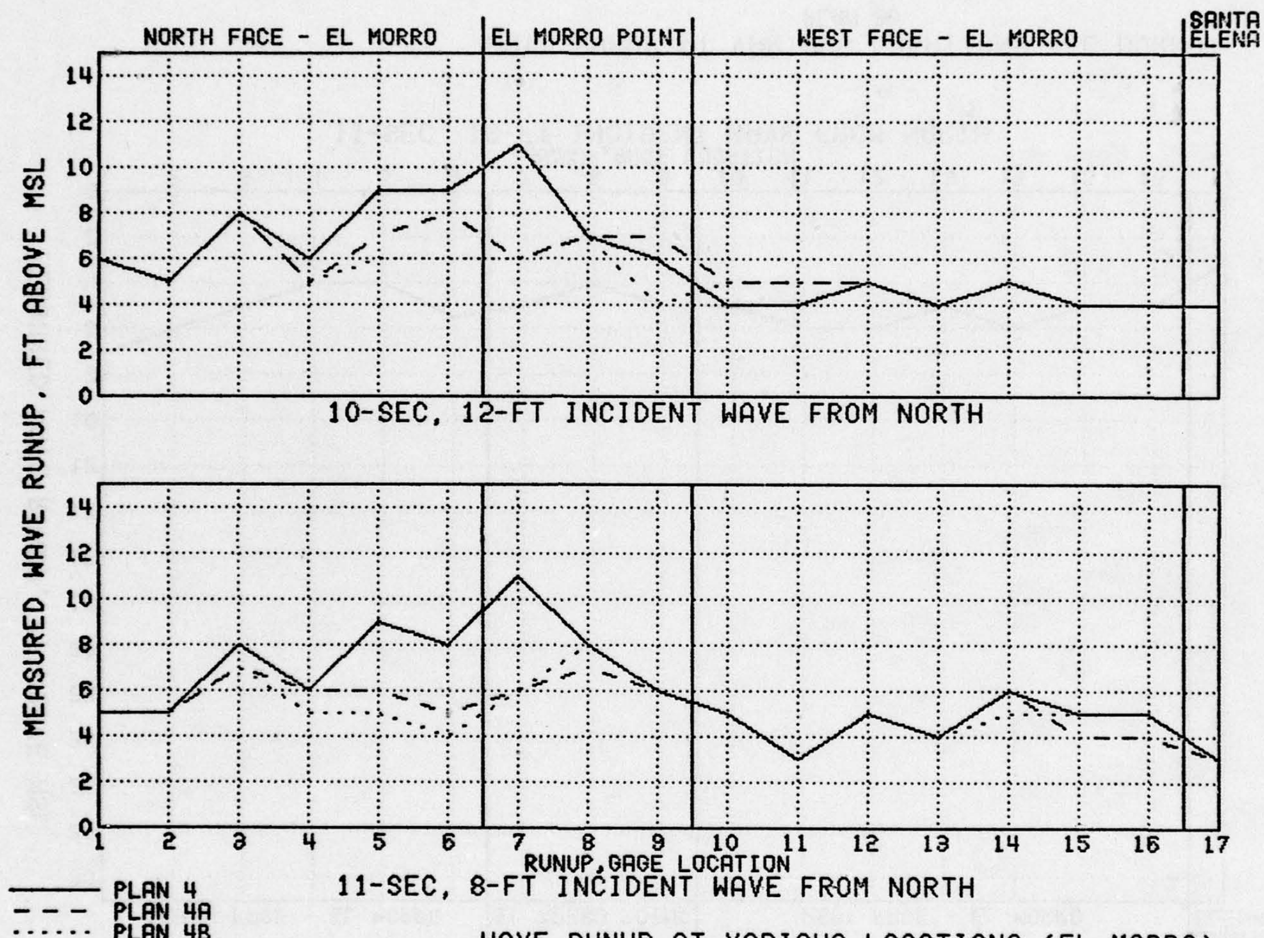
COMPARISON OF WAVE RUNUP VS BREAKWATER CREST ELEVATION FOR PLANS 3–3C



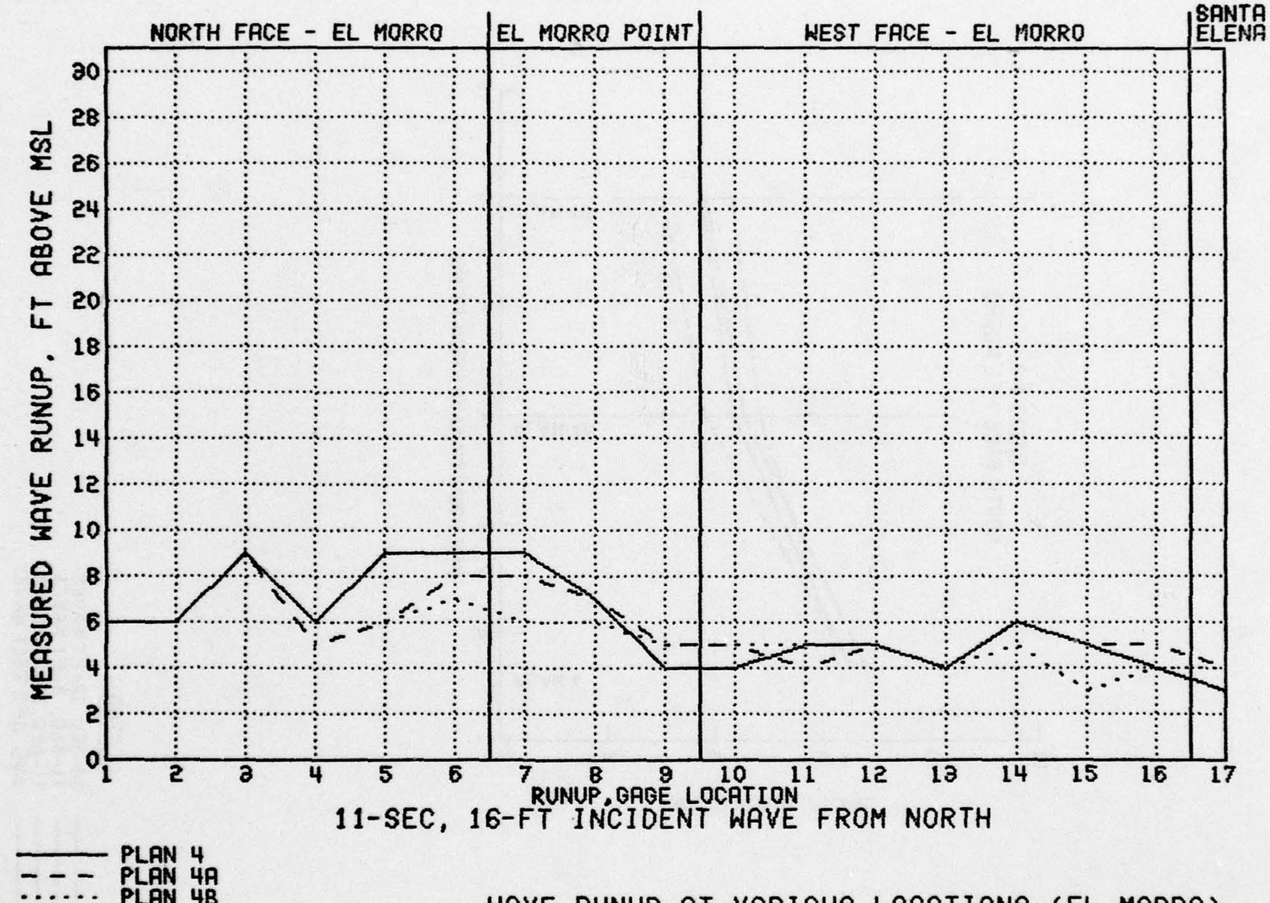
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 3D



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 3D

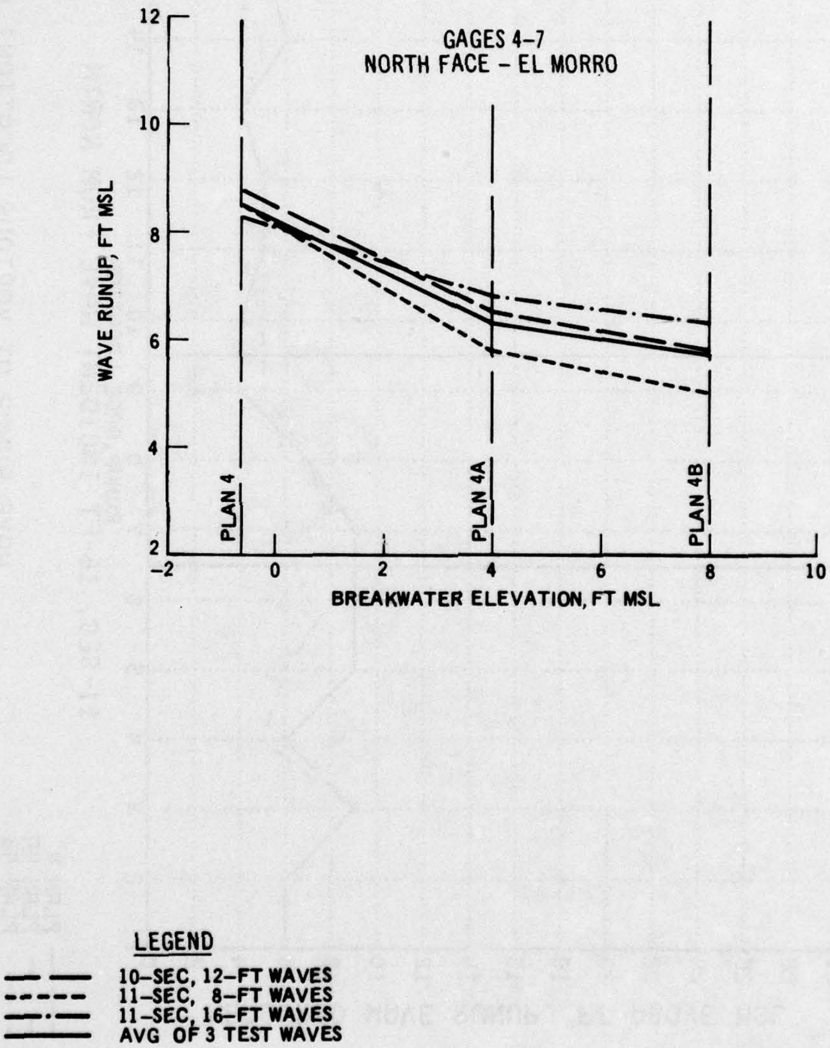


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 4, 4A, AND 4B

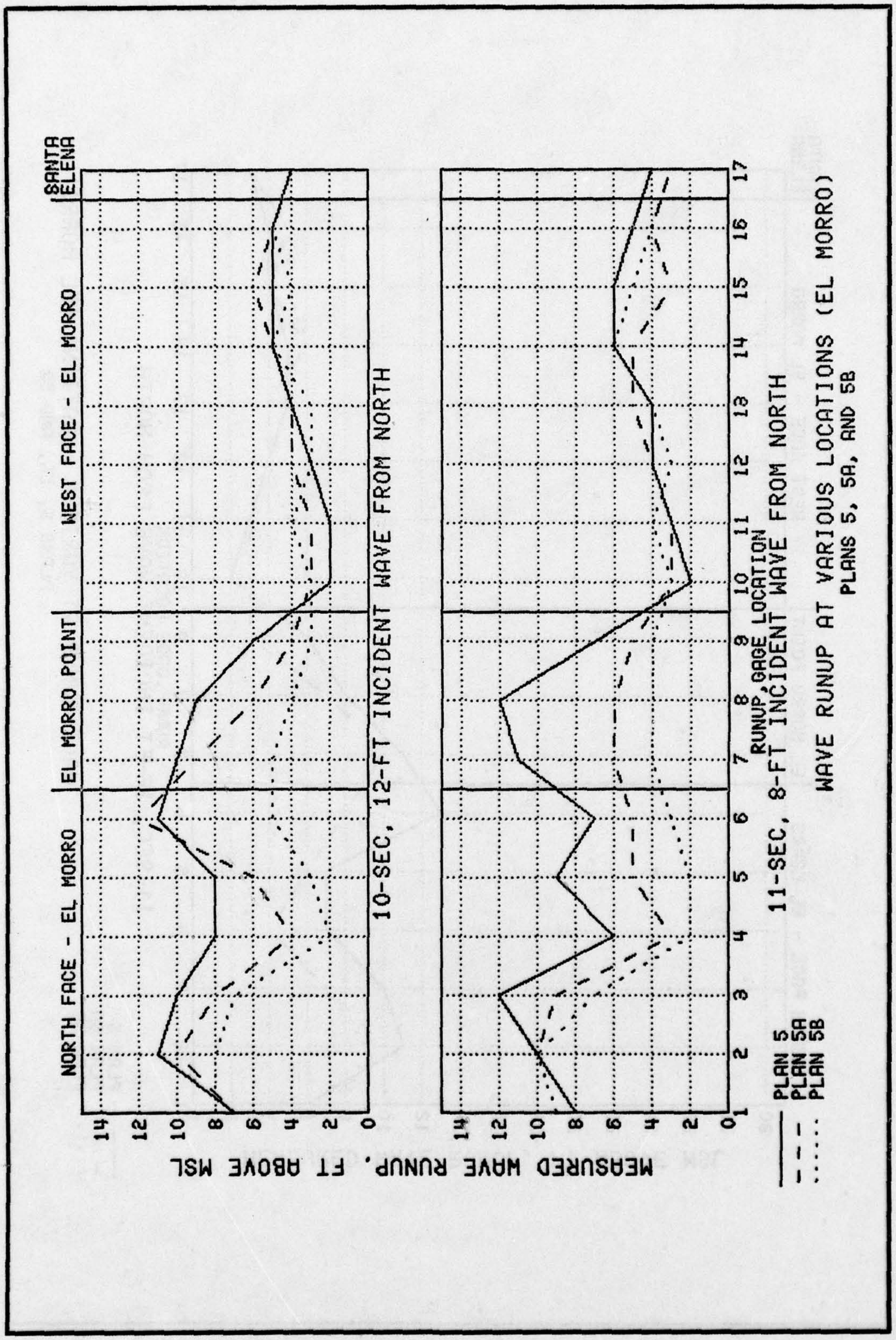


11-SEC, 16-FT INCIDENT WAVE FROM NORTH

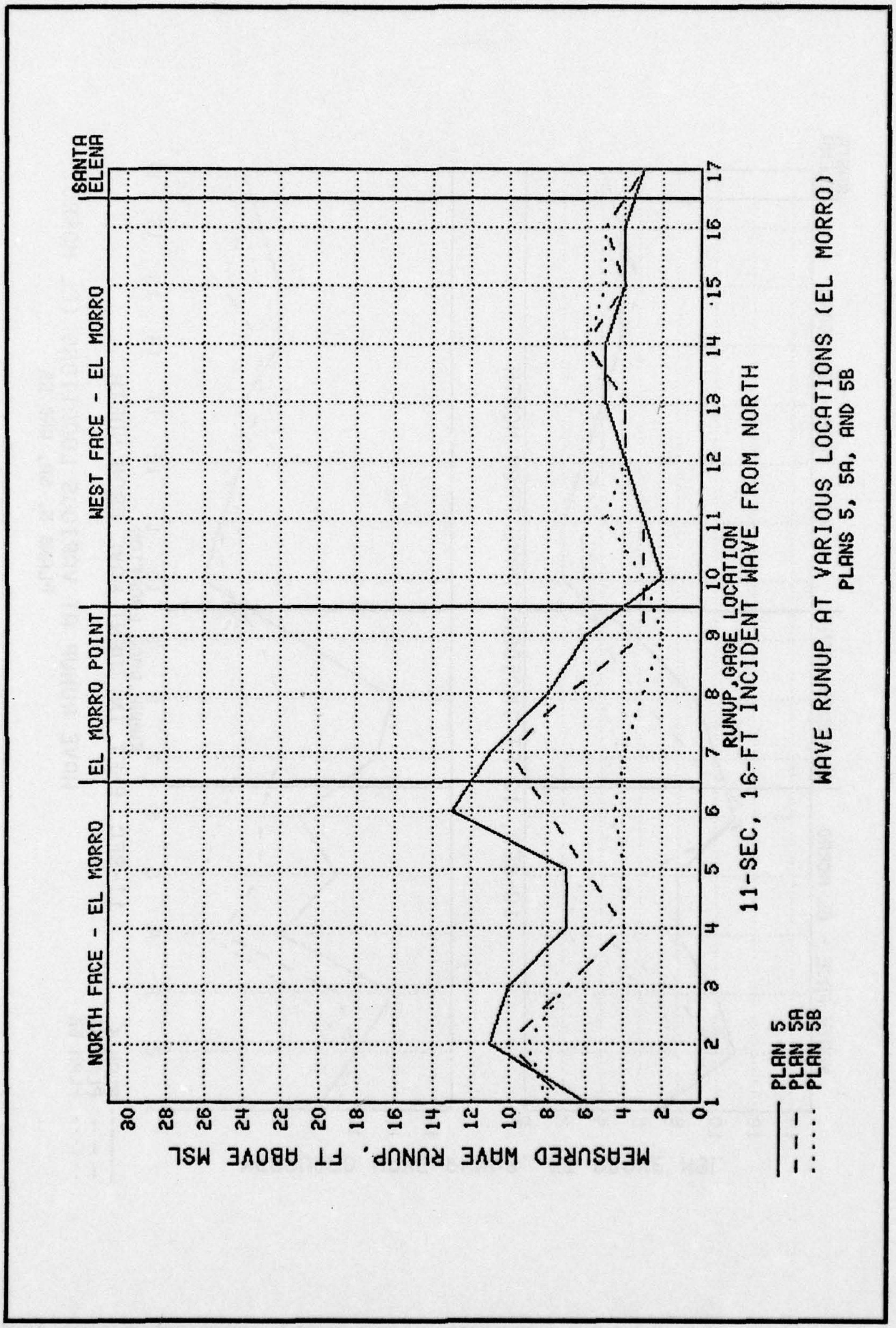
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 4, 4A, AND 4B

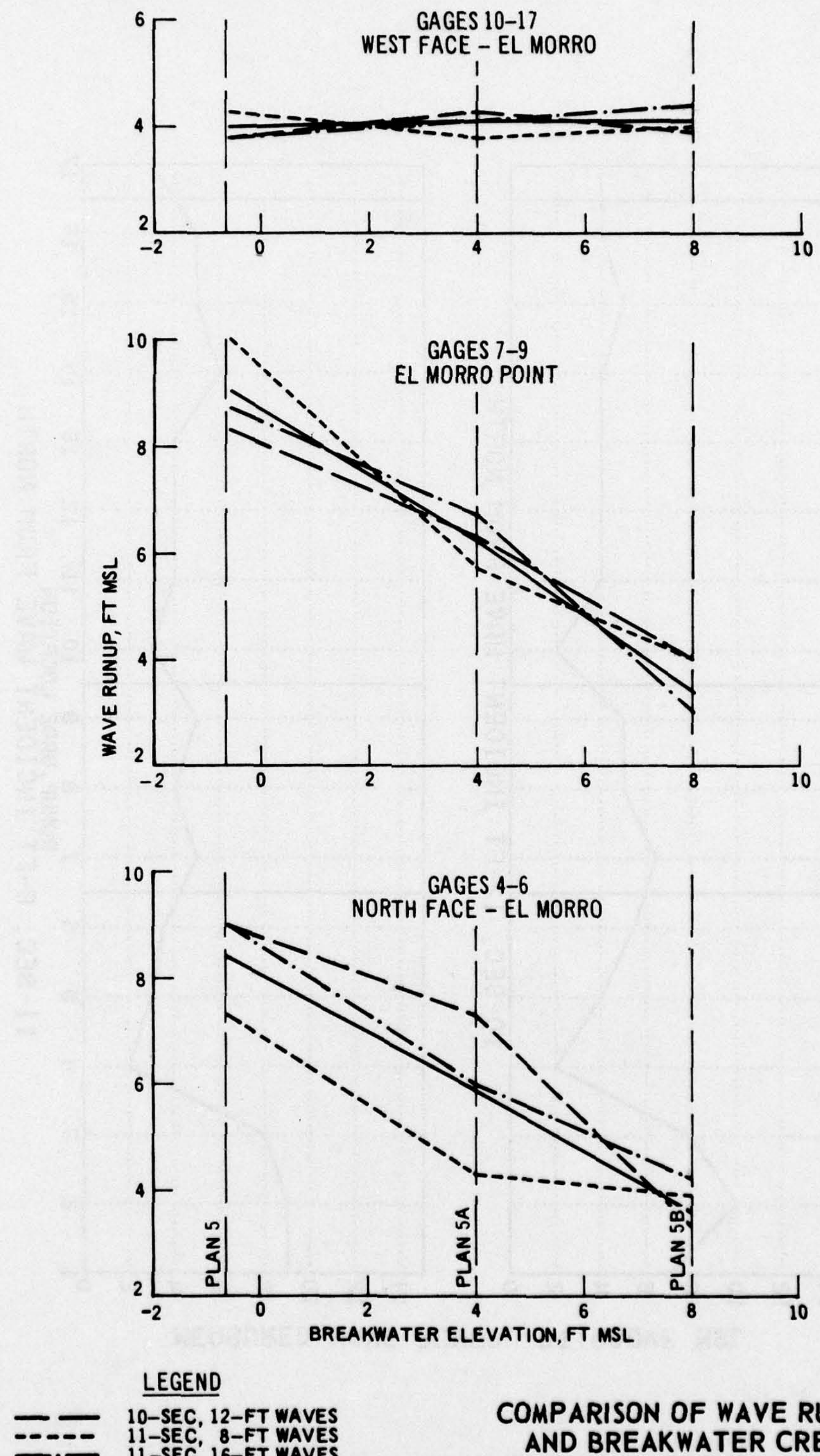


COMPARISON OF WAVE RUNUP VS BREAKWATER CREST ELEVATION FOR PLANS 4-4B

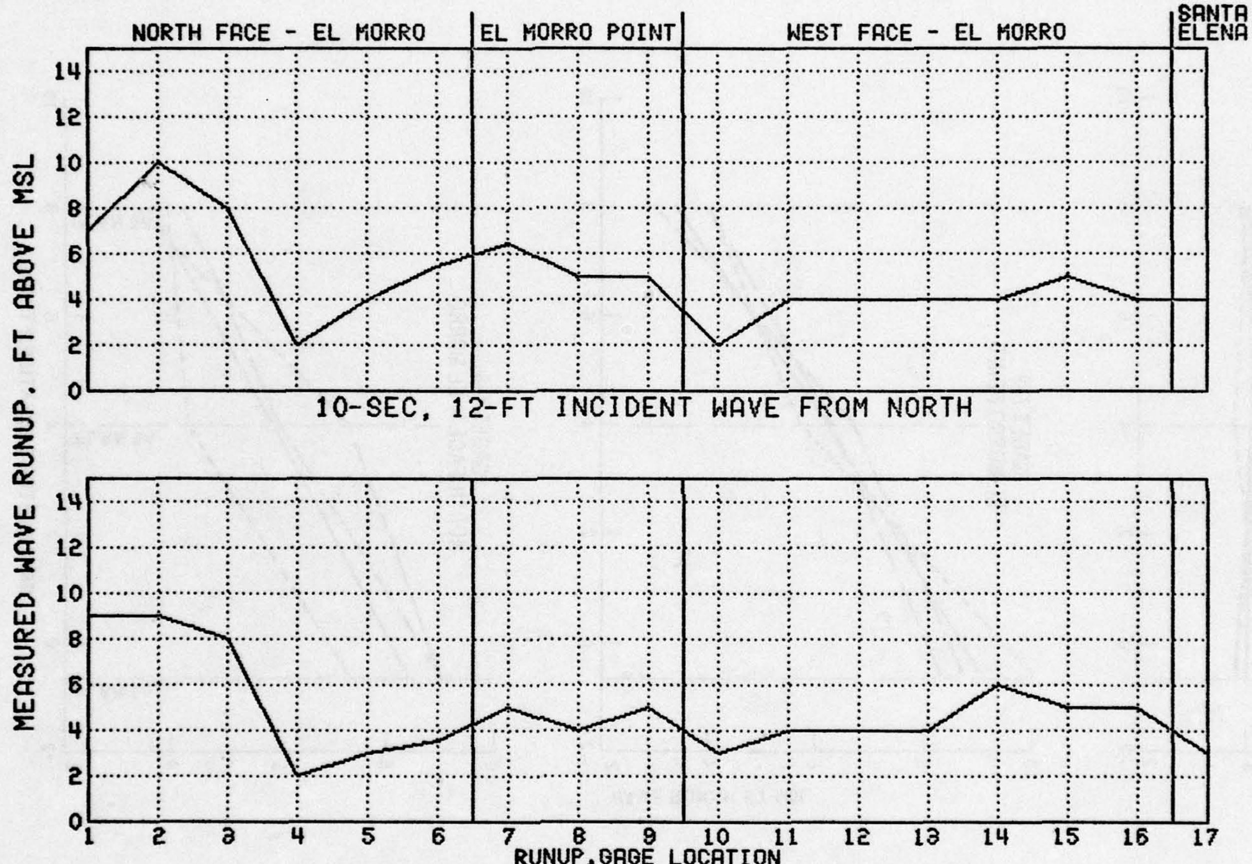


MEASURED WAVE RUNUP, FT ABOVE MSL
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
10-SEC, 12-FT INCIDENT WAVE FROM NORTH
11-SEC, 8-FT INCIDENT WAVE FROM NORTH
RUNUP GAGE LOCATION
PLAN 5
PLAN 5A
PLAN 5B
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 5, 5A, AND 5B


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
30 28 26 24 22 20 18 16 14 12 10 8 6 4 2 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
RUNUP GAGE LOCATION
11-SEC, 16-FT INCIDENT WAVE FROM NORTH
PLAN 5
PLAN 5A
PLAN 5B
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 5, 5A, AND 5B

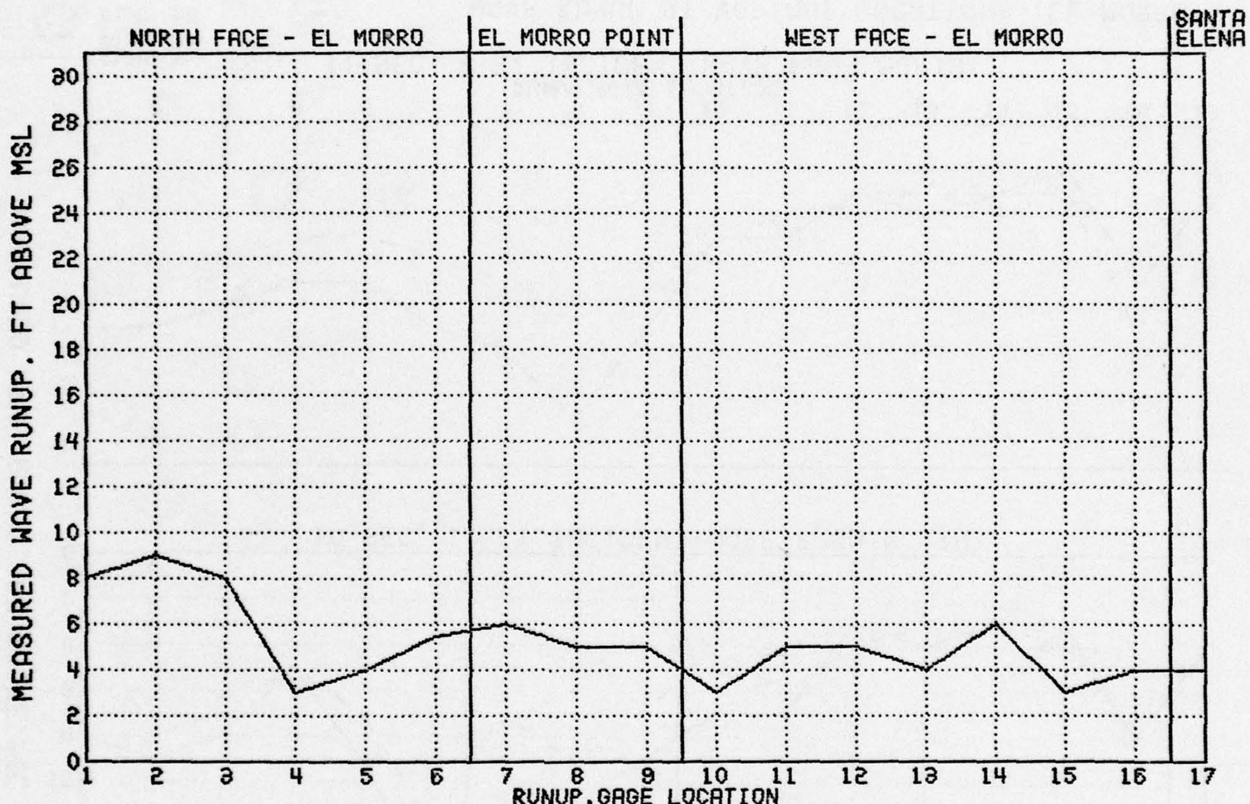


COMPARISON OF WAVE RUNUP AND BREAKWATER CREST ELEVATION FOR PLANS 5-5B



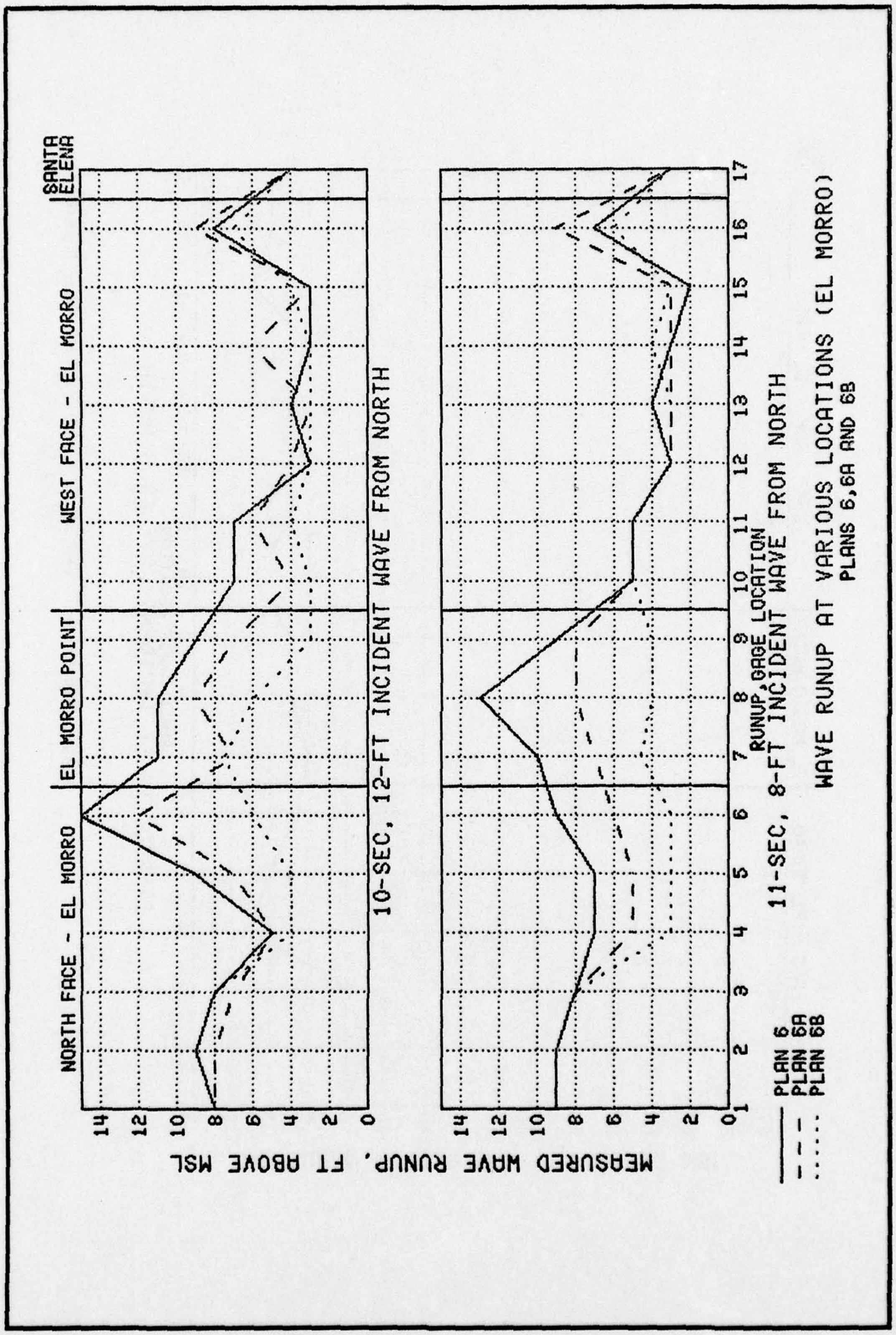
11-SEC, 8-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 5C



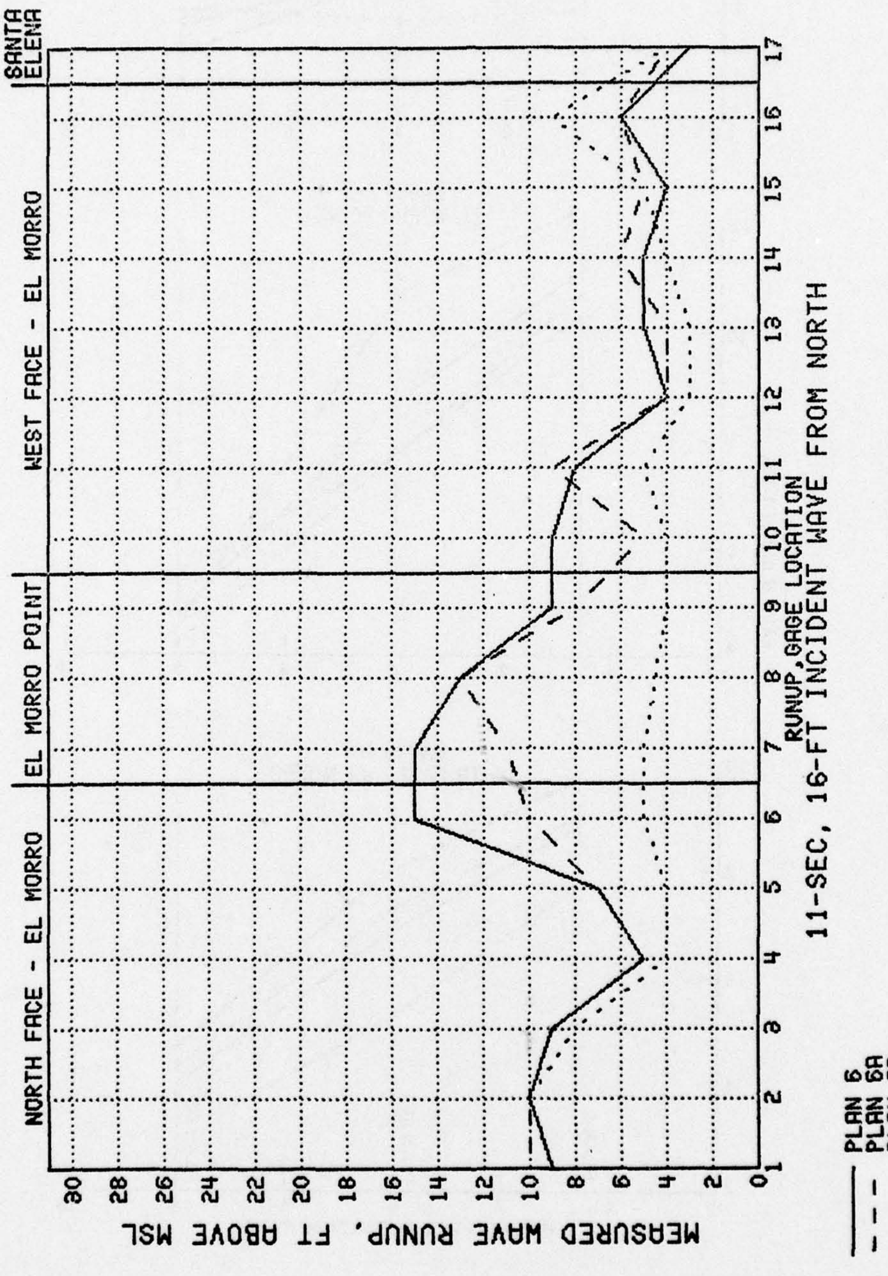
11-SEC, 16-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 5C

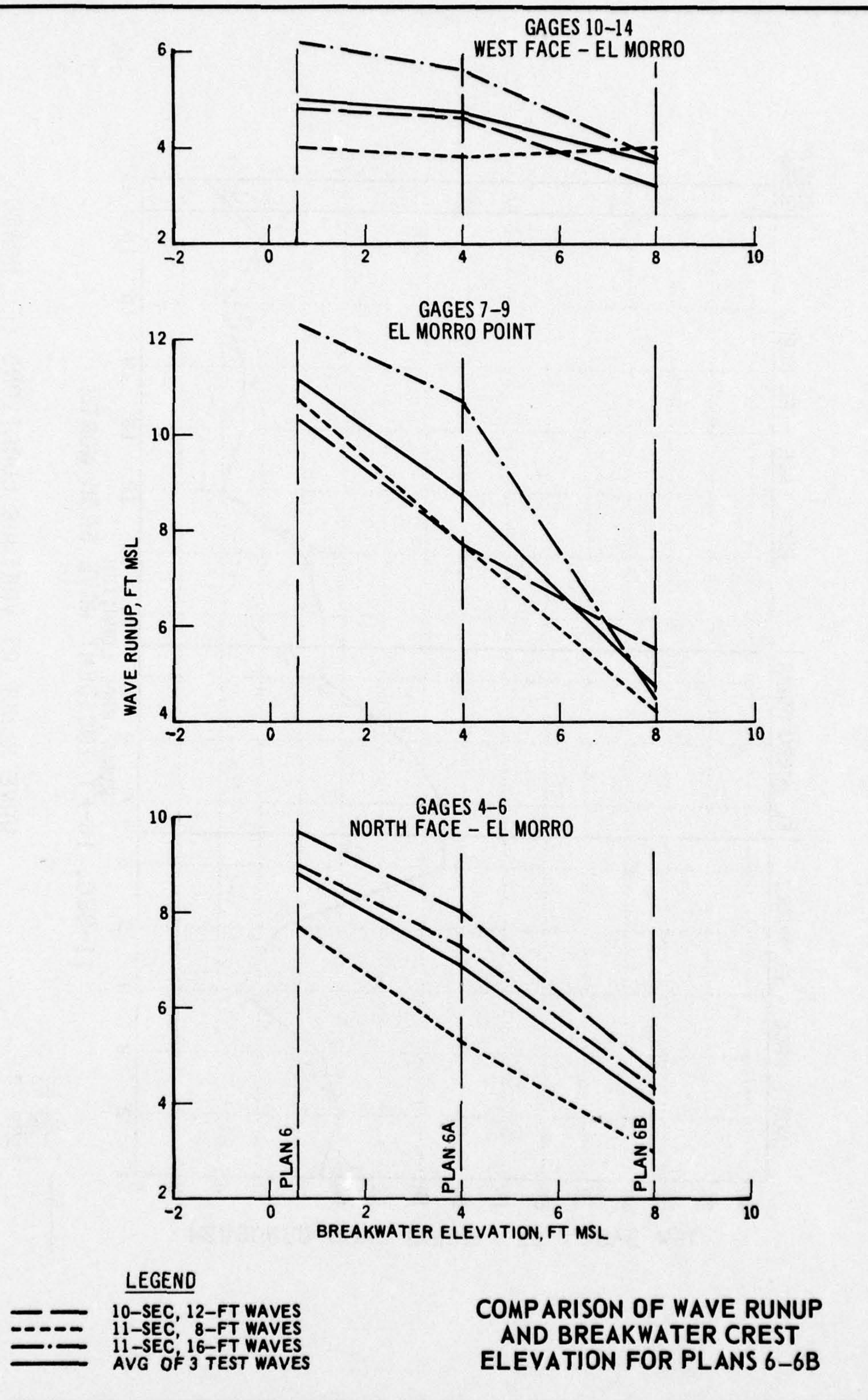


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 6,6A AND 6B

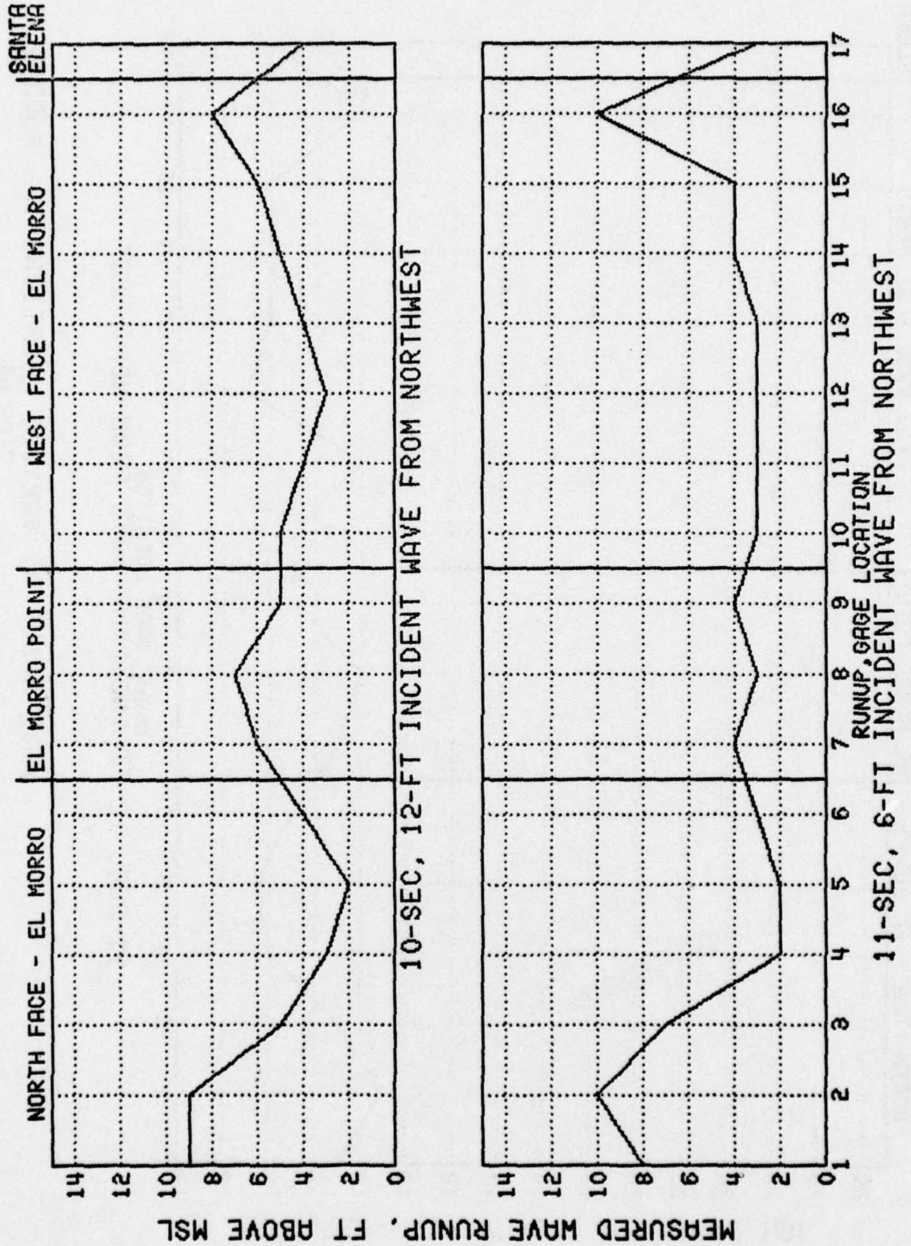
PLATE 108



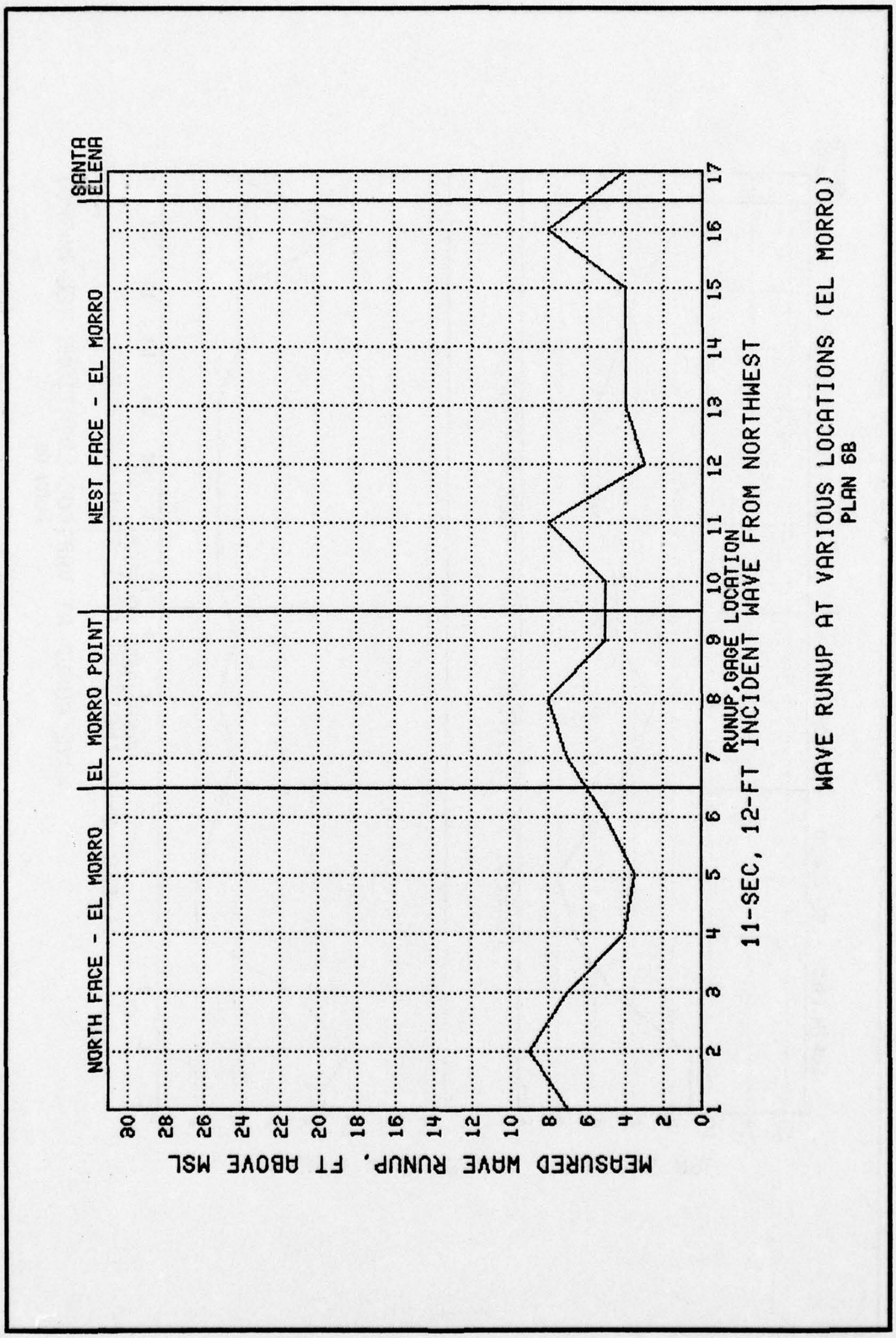
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 6,6A AND 6B



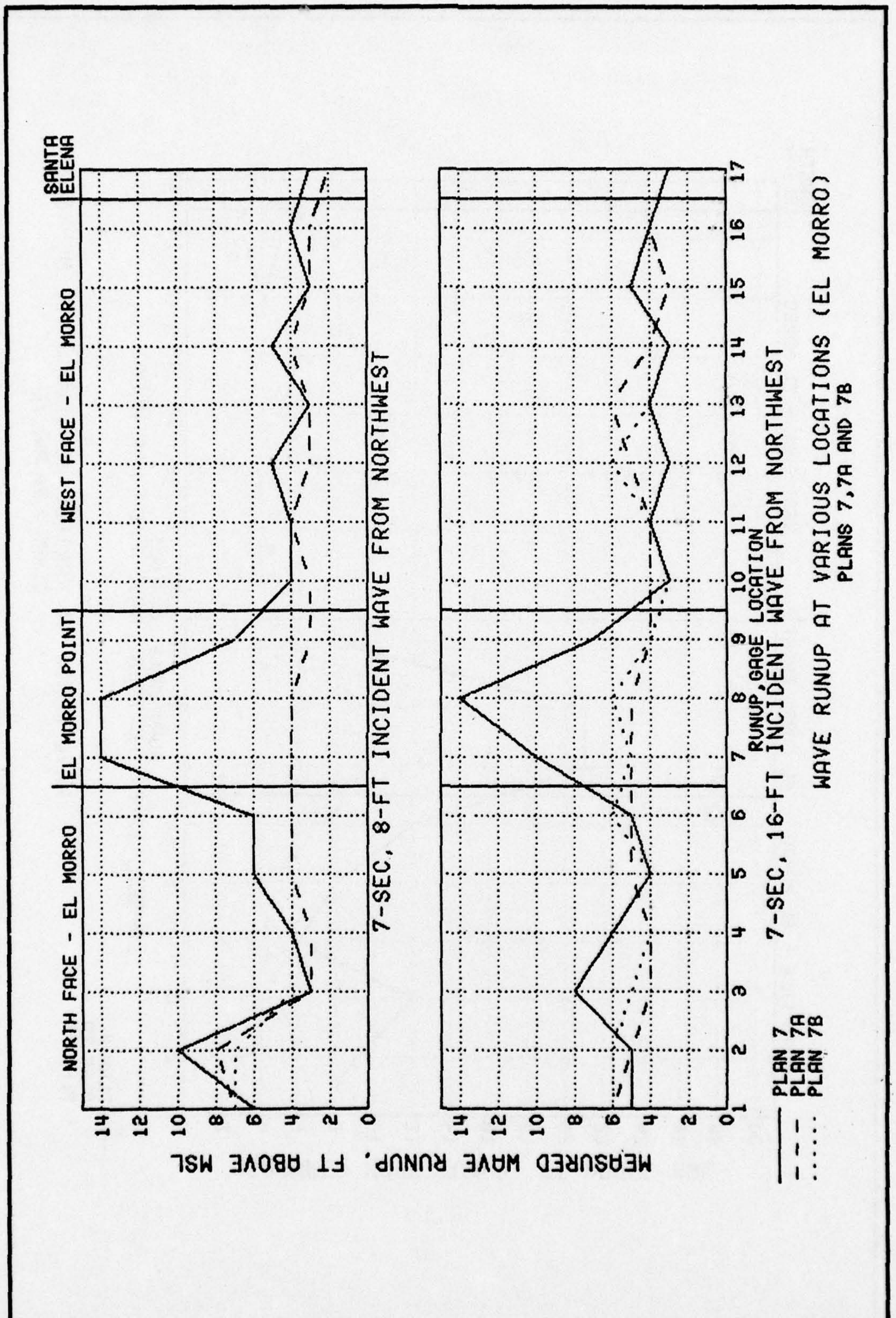
COMPARISON OF WAVE RUNUP AND BREAKWATER CREST ELEVATION FOR PLANS 6–6B



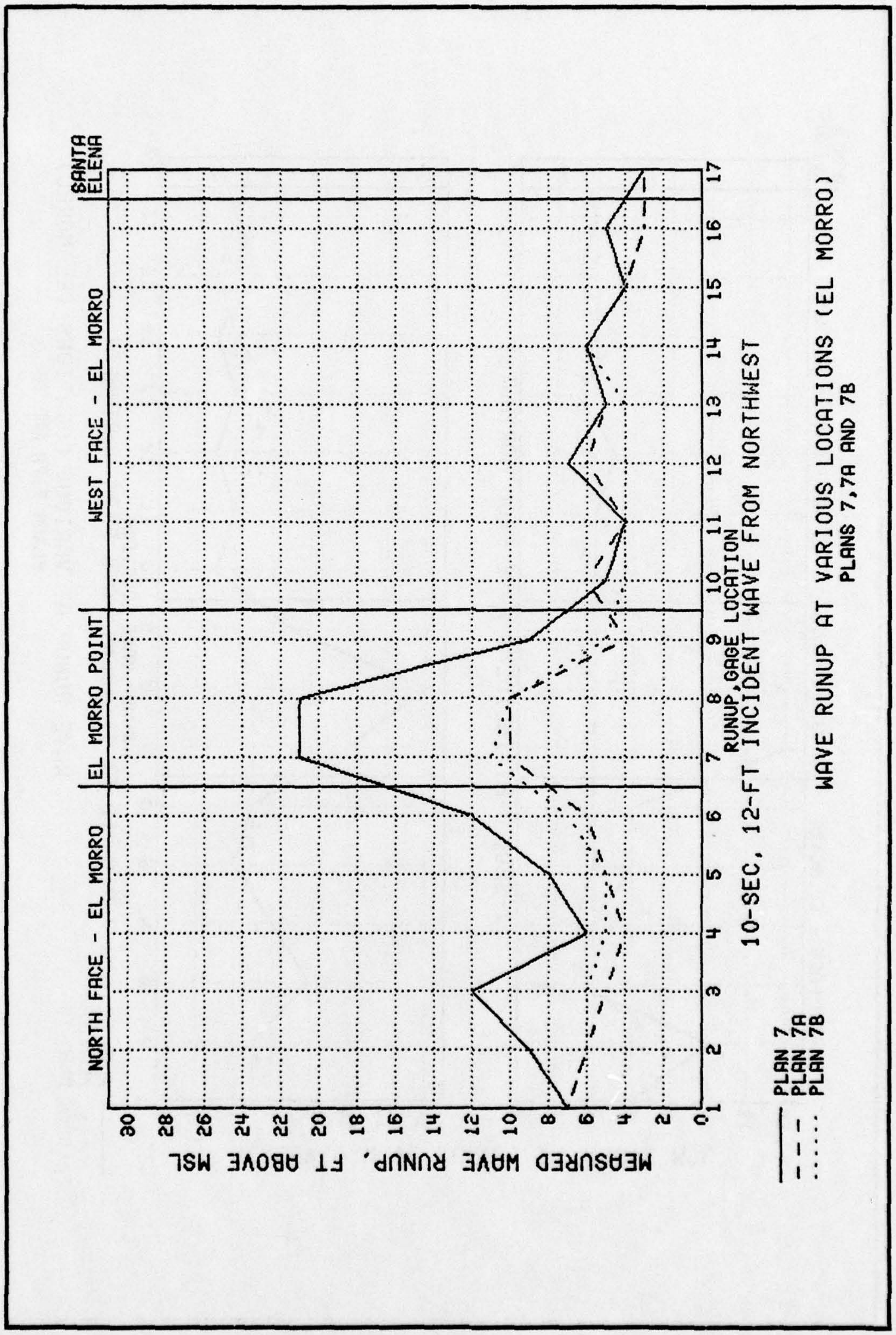
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 6B



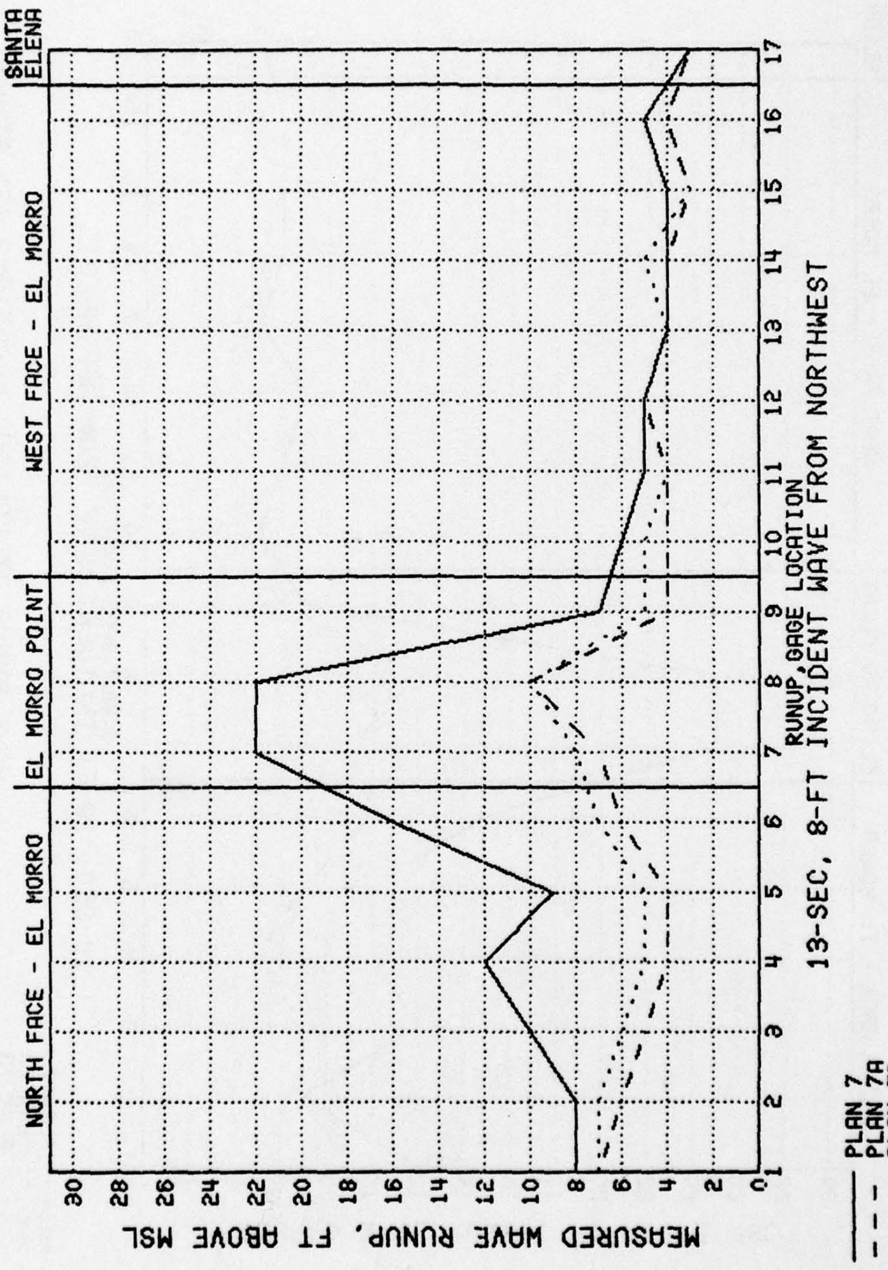
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
11-SEC, 12-FT INCIDENT WAVE FROM NORTHWEST
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 6B



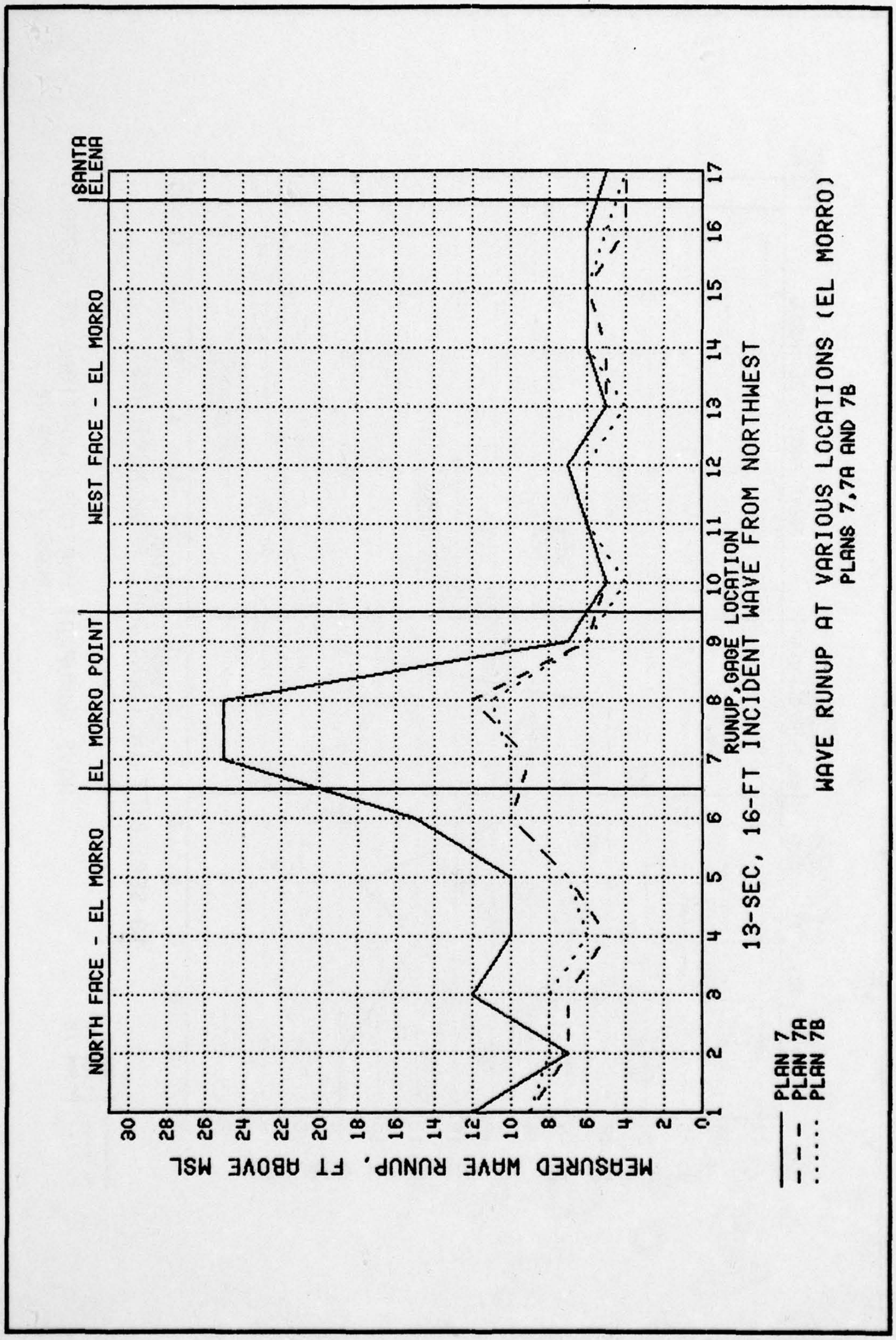
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B

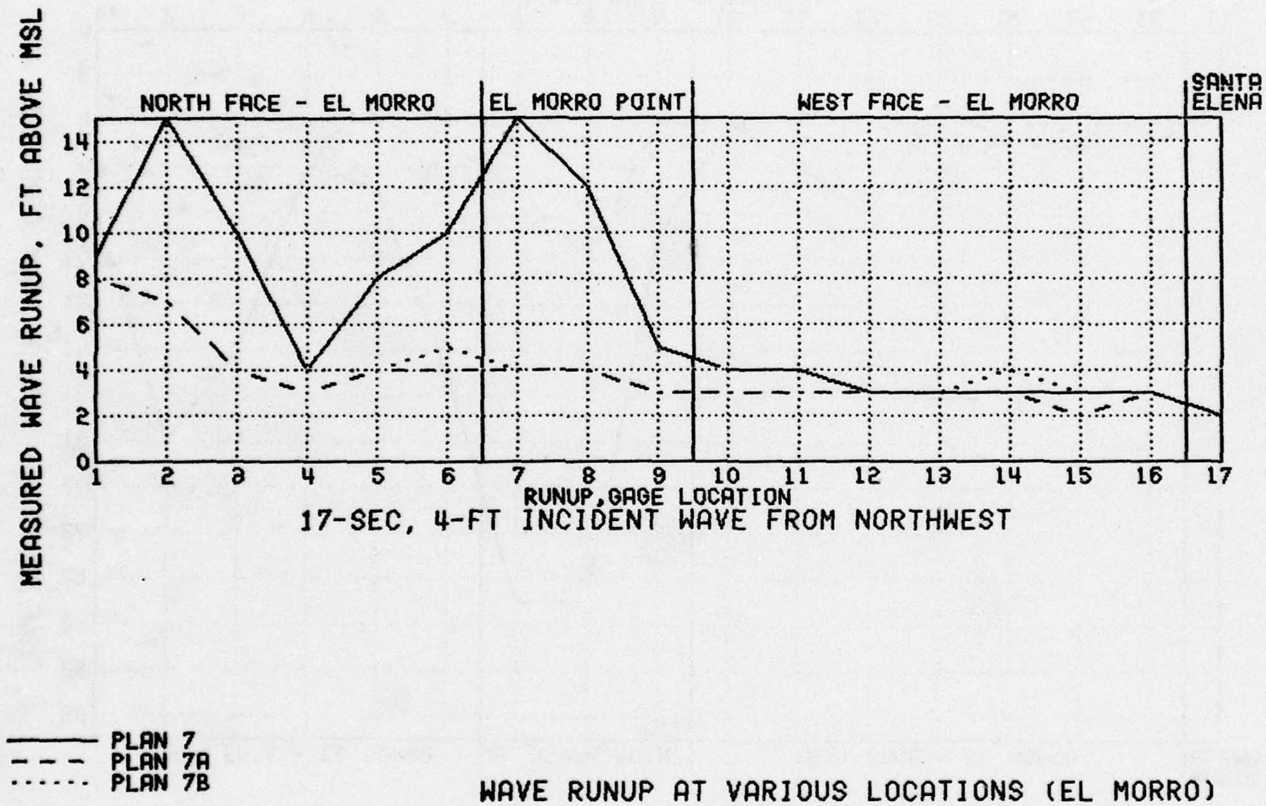


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B



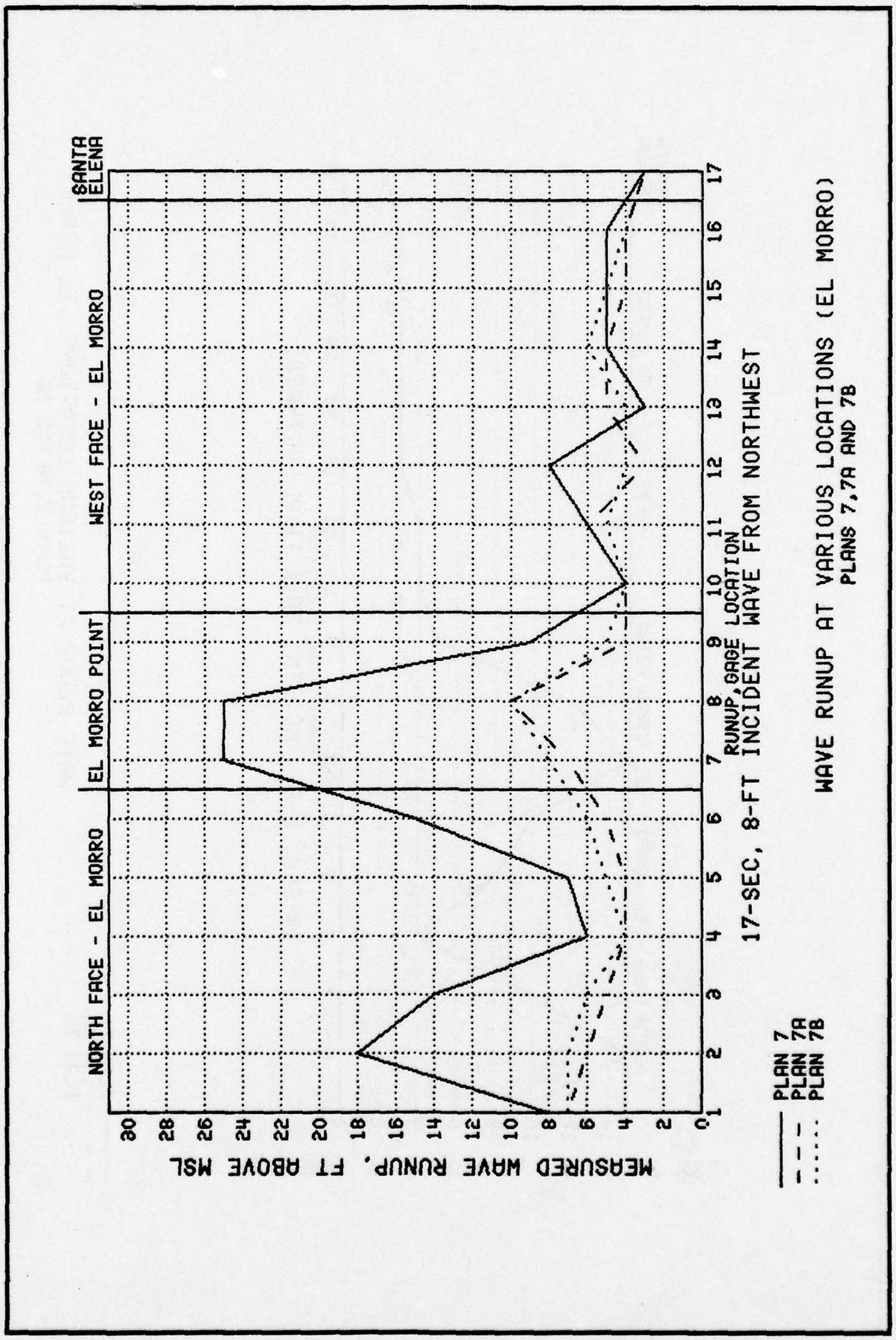
13-SEC, 16-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B



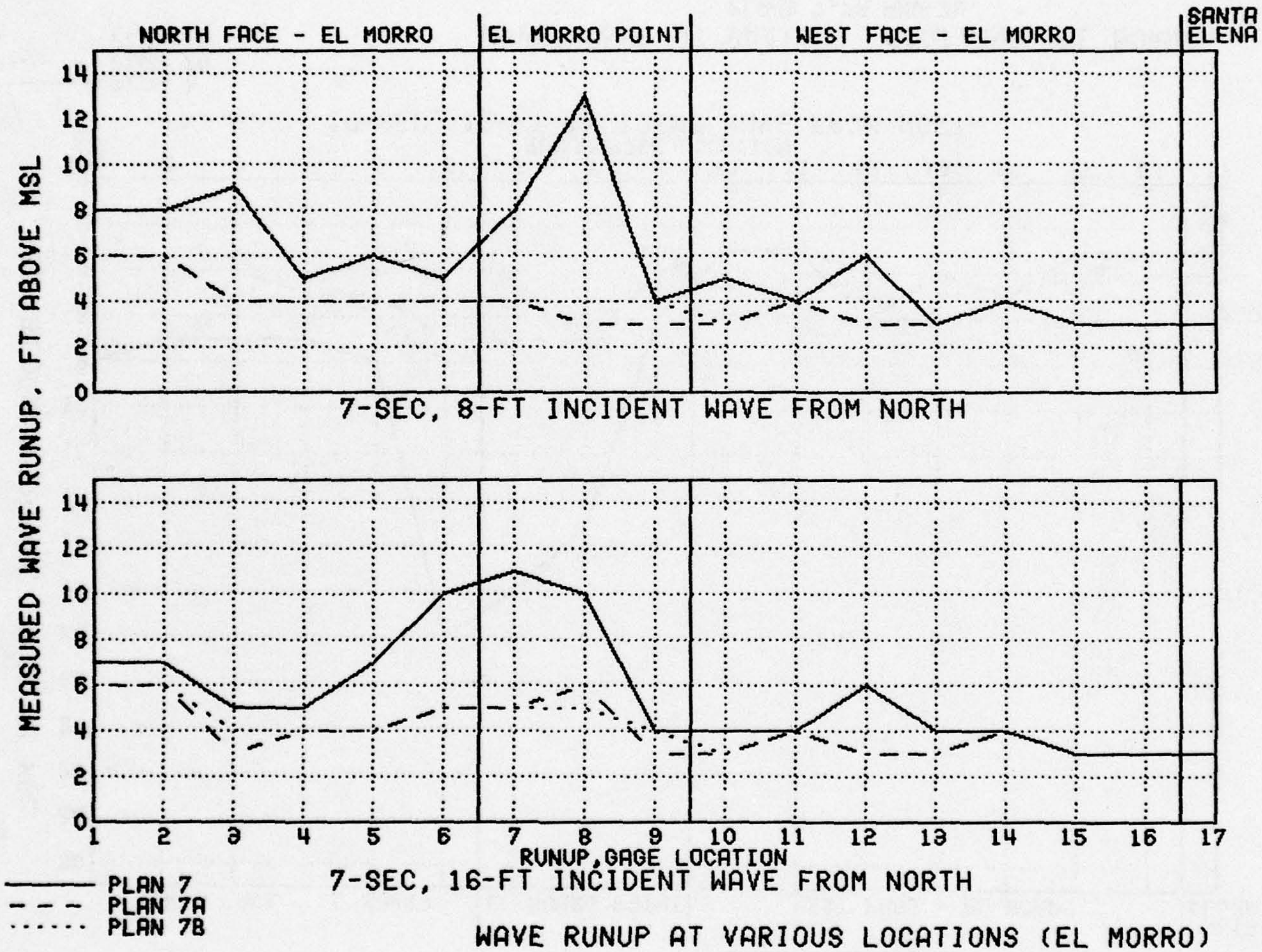
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)

PLANS 7,7A AND 7B

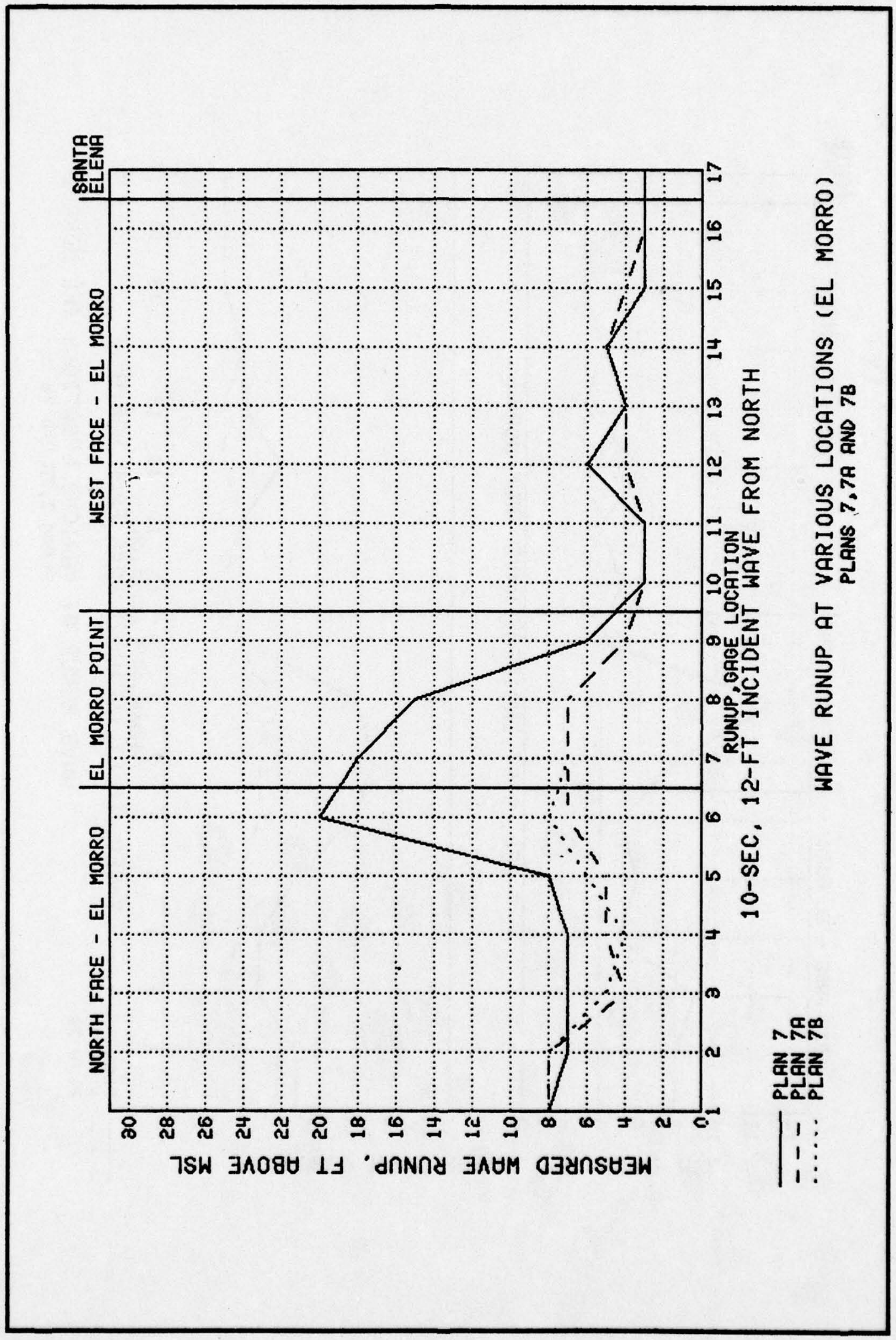


17-SEC, 8-FT INCIDENT WAVE FROM NORTHWEST

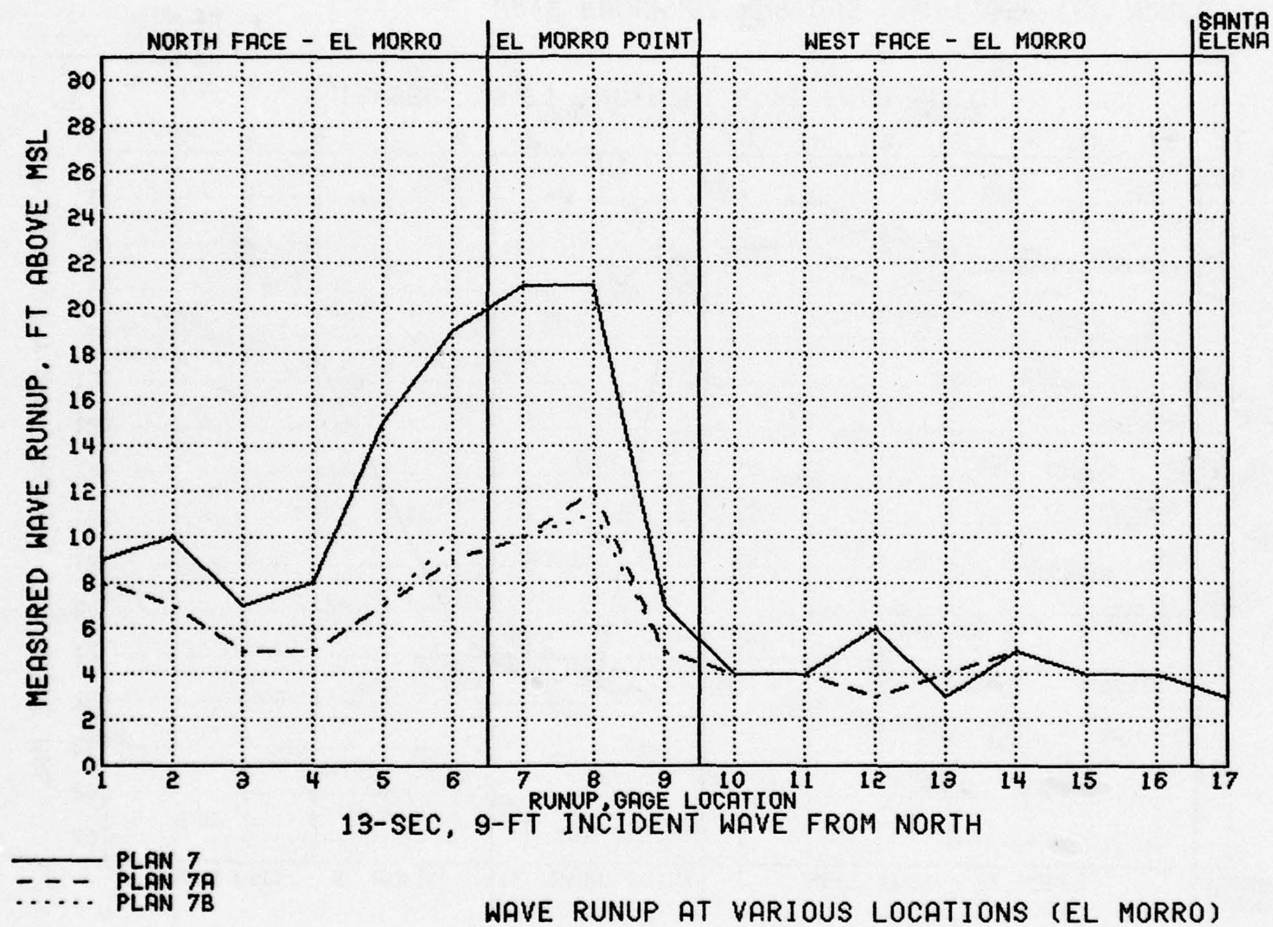
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B

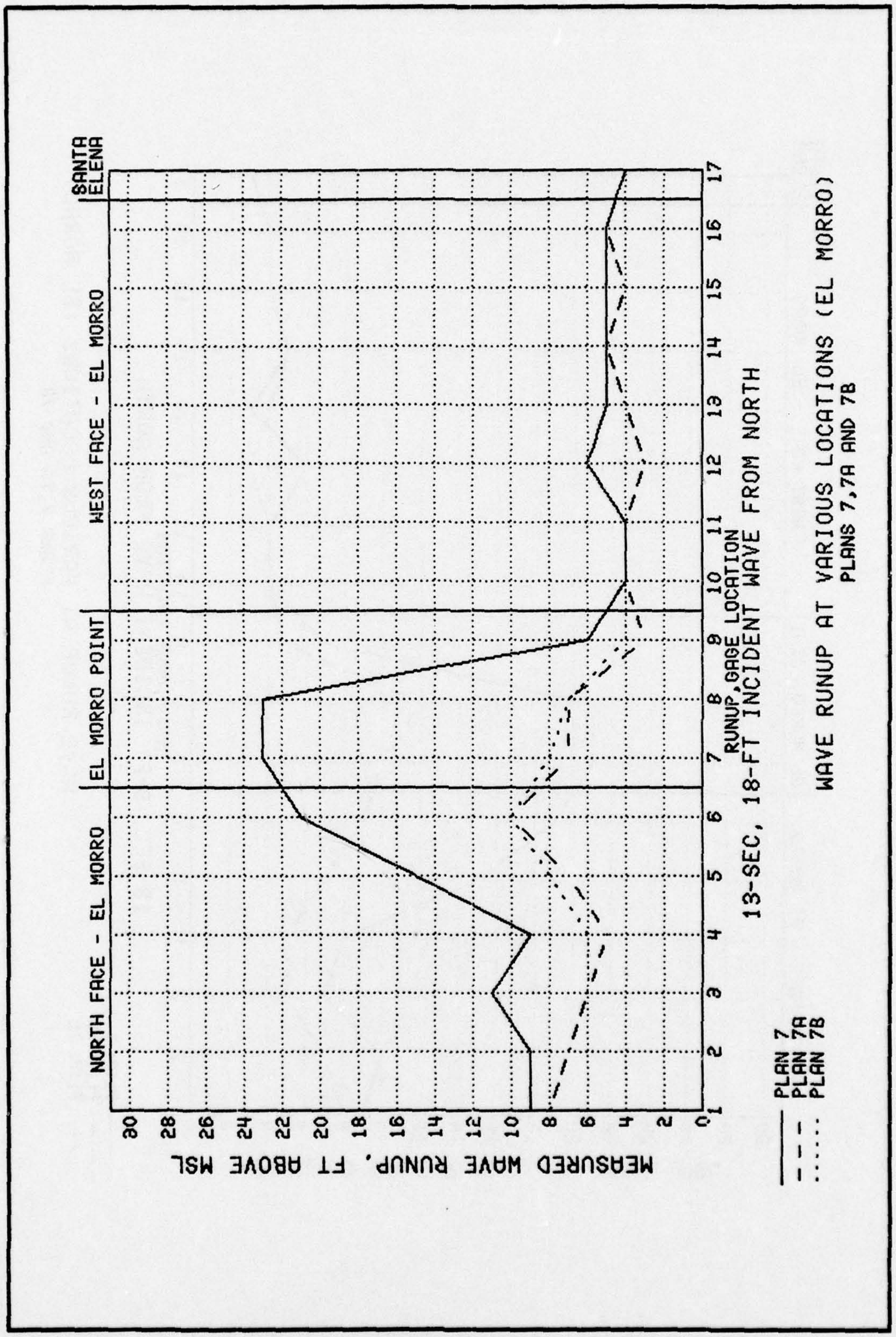


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
RUNUP,GAGE LOCATION
10-SEC, 12-FT INCIDENT WAVE FROM NORTH
PLAN 7
PLAN 7A
PLAN 7B
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B

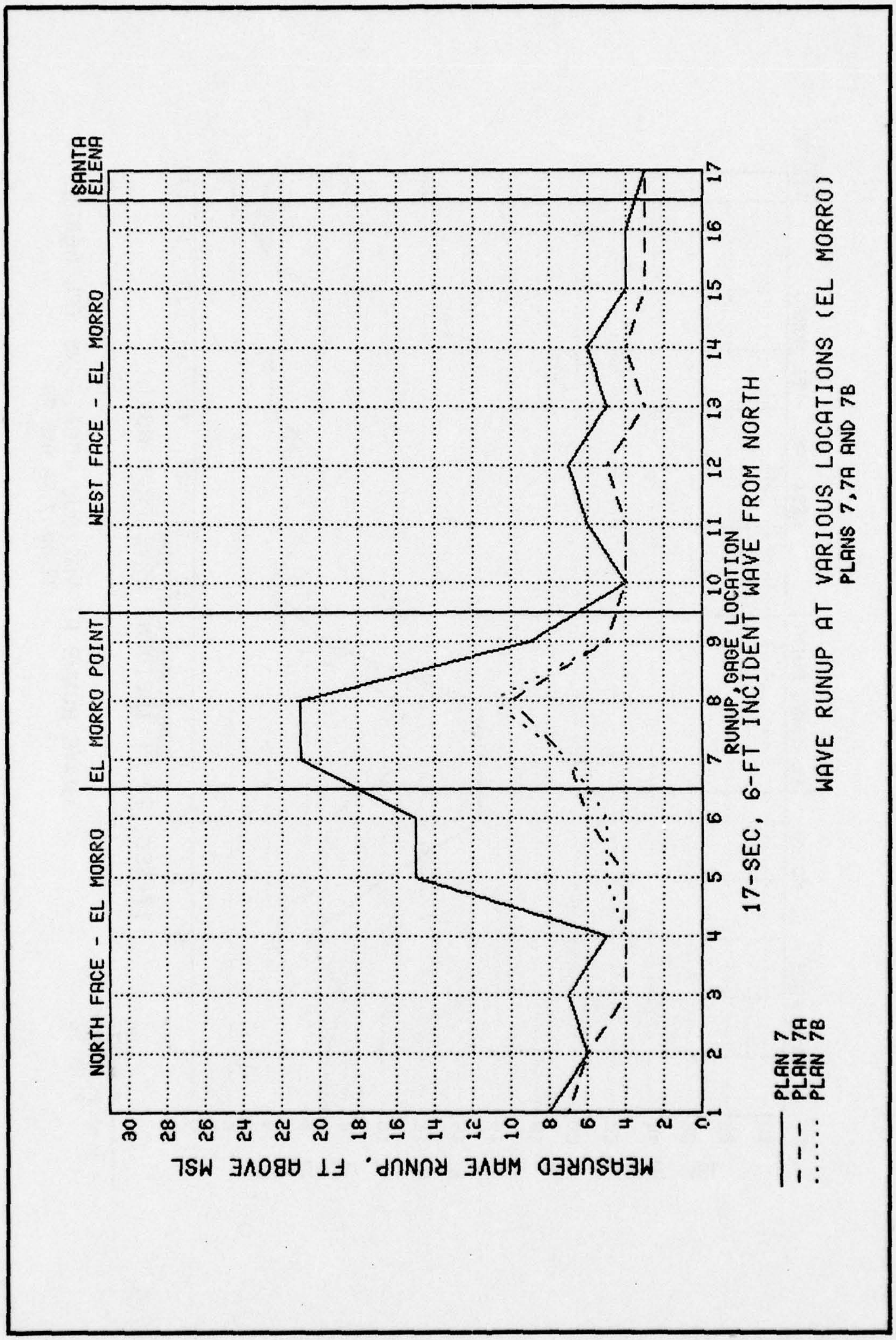


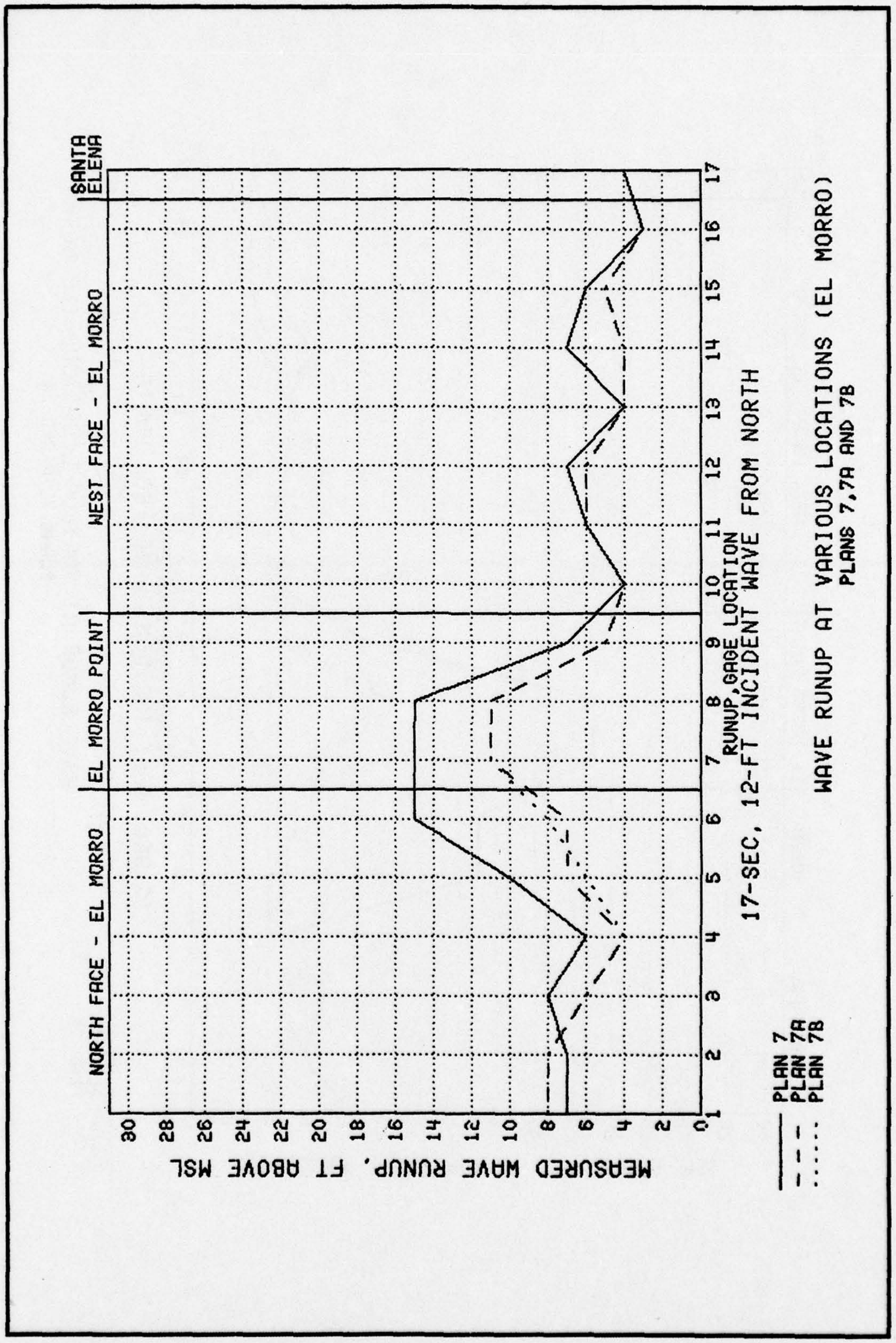
13-SEC, 9-FT INCIDENT WAVE FROM NORTH

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B

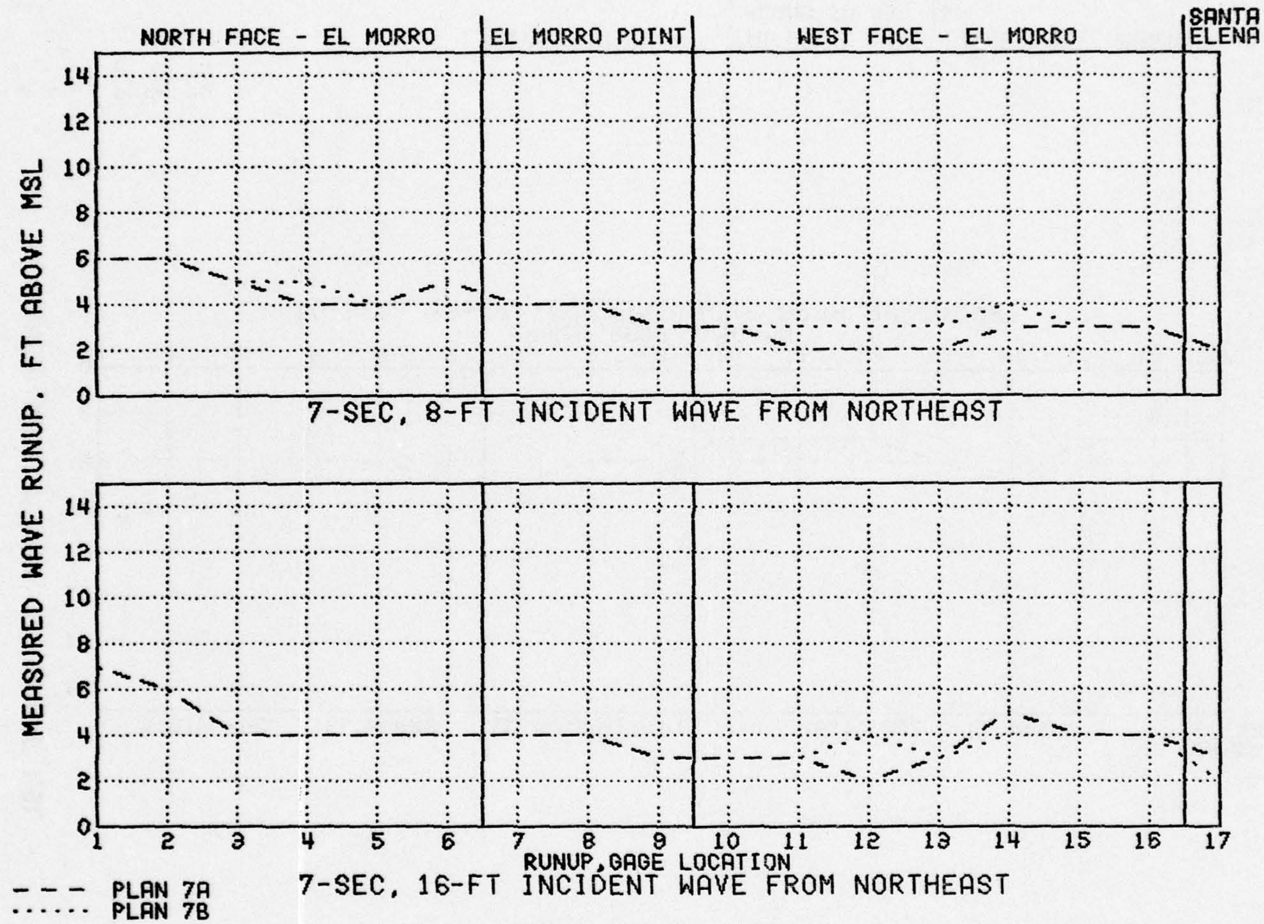


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP,GAGE LOCATION
13-SEC, 18-FT INCIDENT WAVE FROM NORTH
PLAN 7
PLAN 7A
PLAN 7B
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B

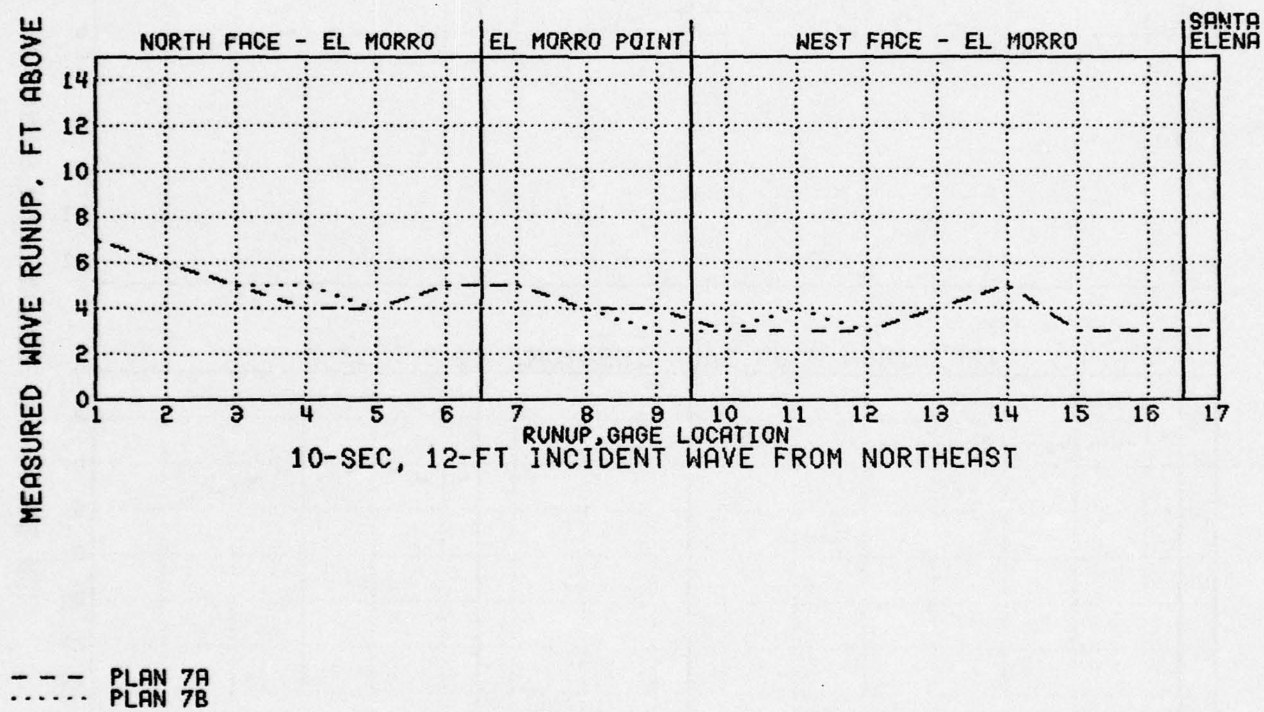

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
PLAN 7
PLAN 7A
PLAN 7B
17-SEC, 6-FT INCIDENT WAVE FROM NORTH
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B



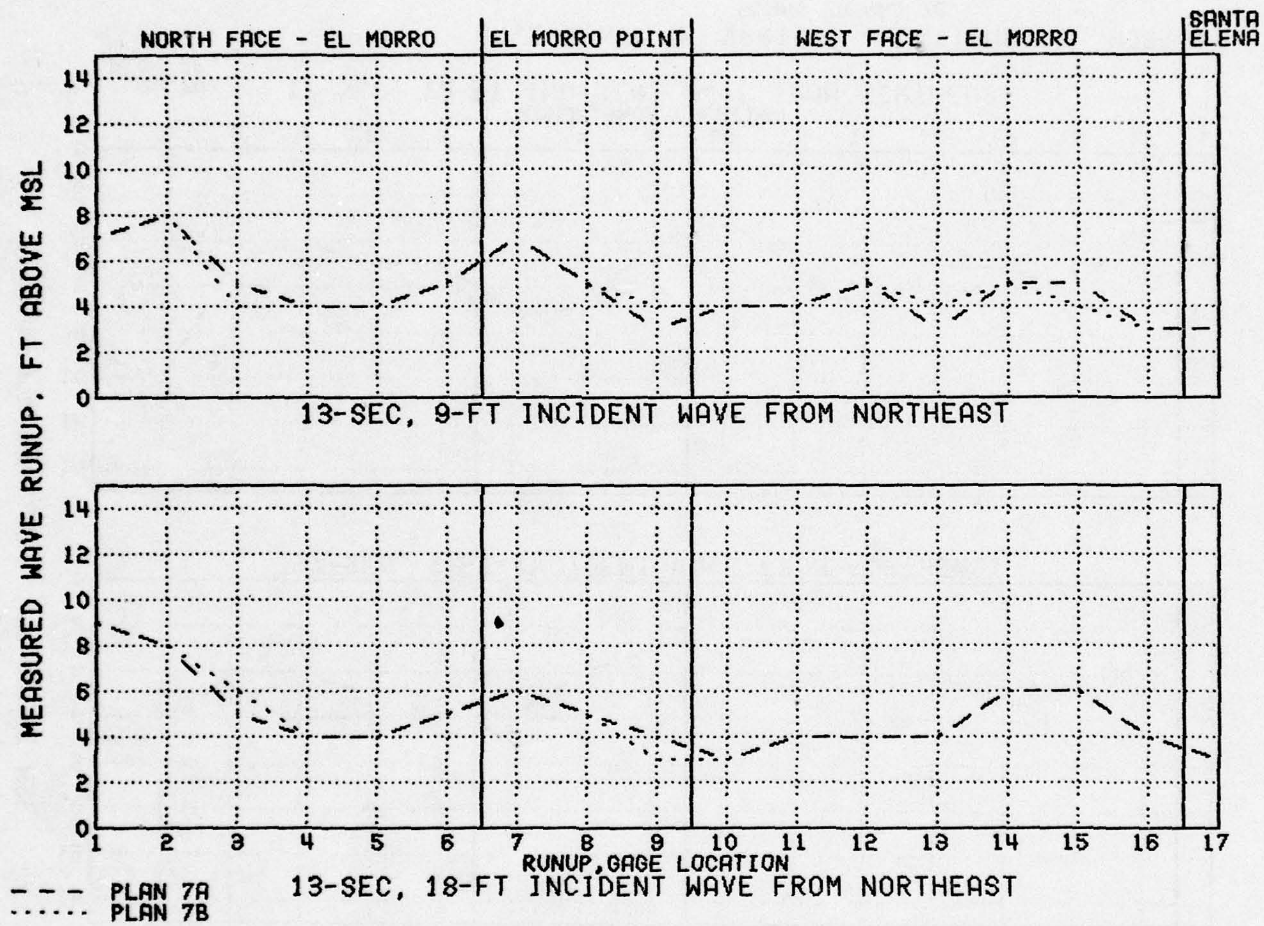
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7,7A AND 7B



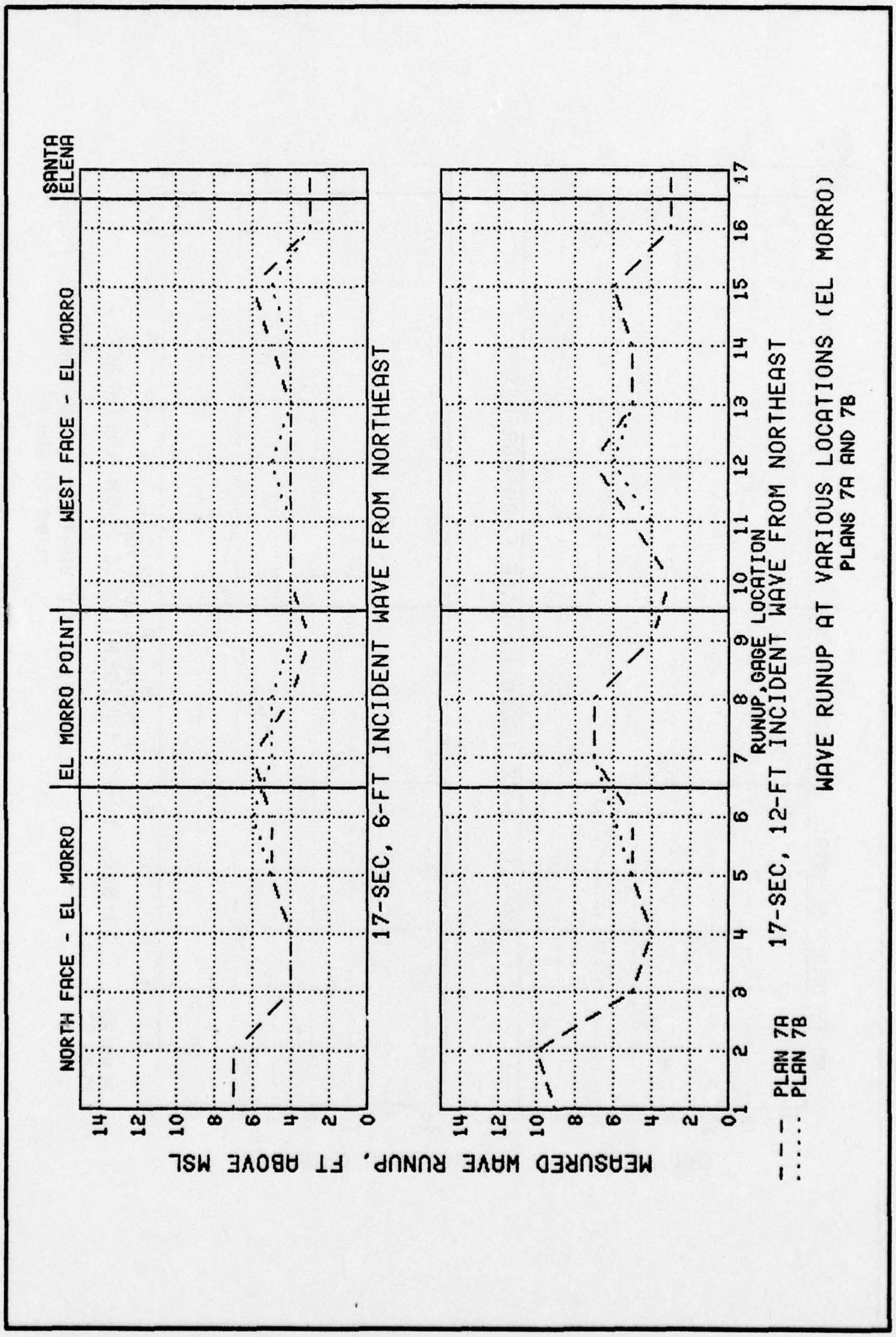
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A AND 7B



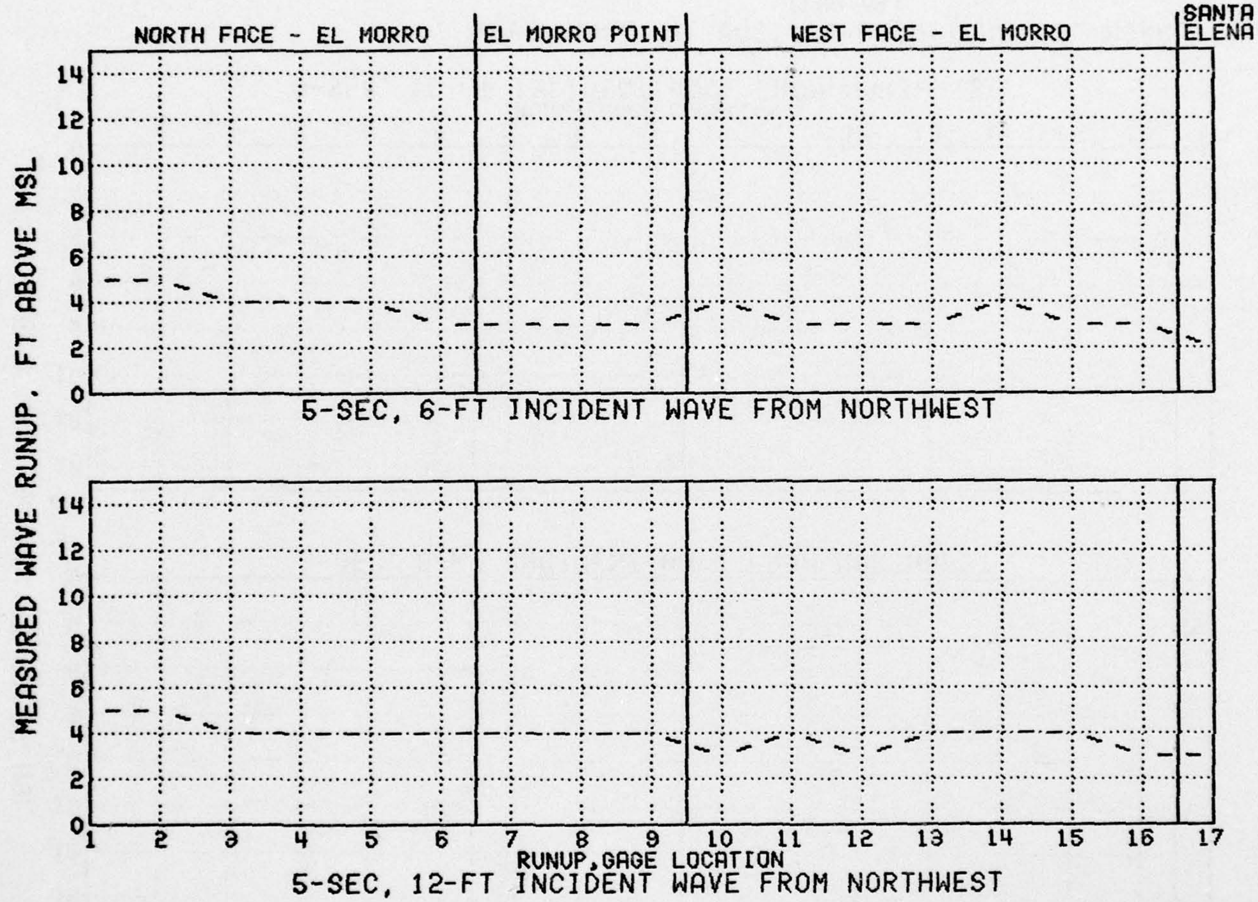
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A AND 7B



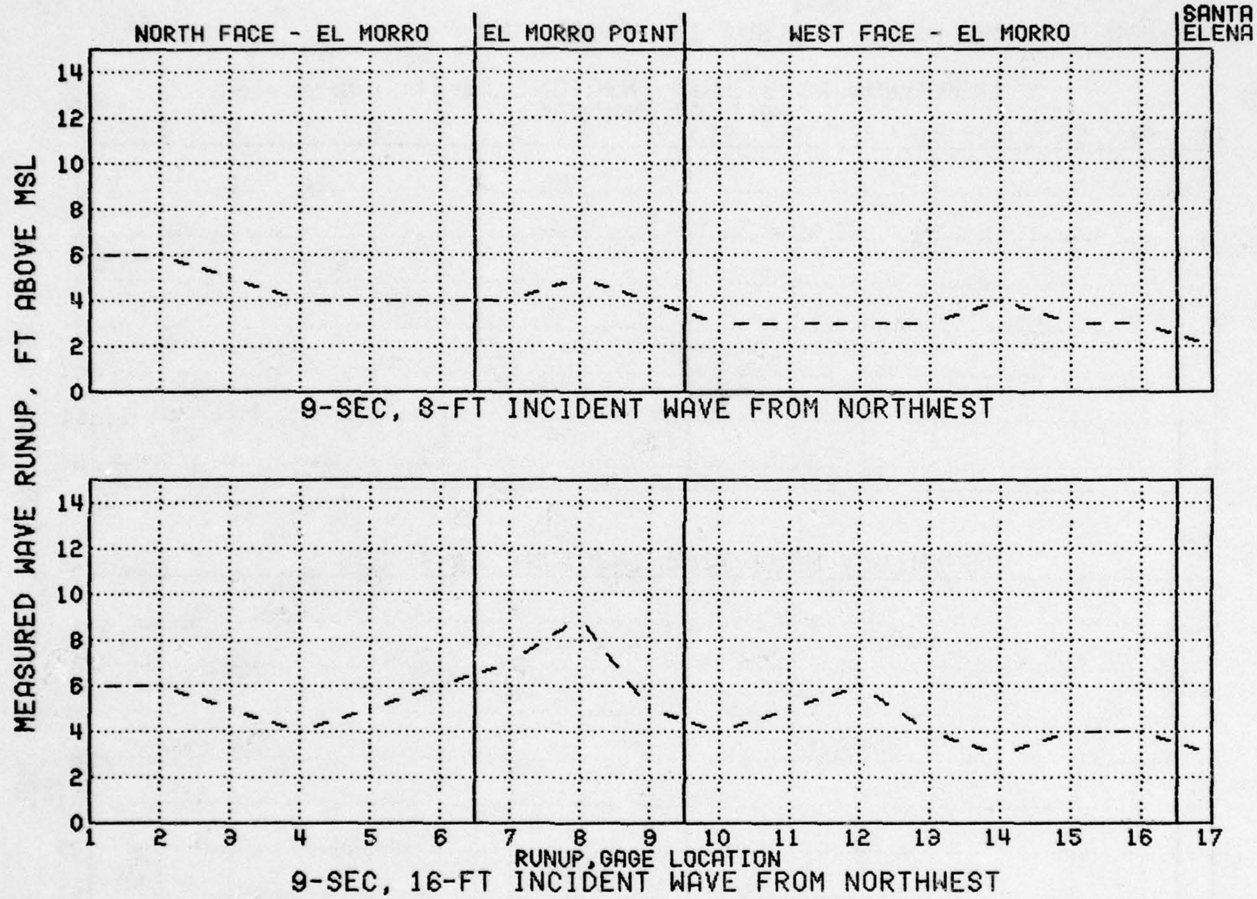
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A AND 7B



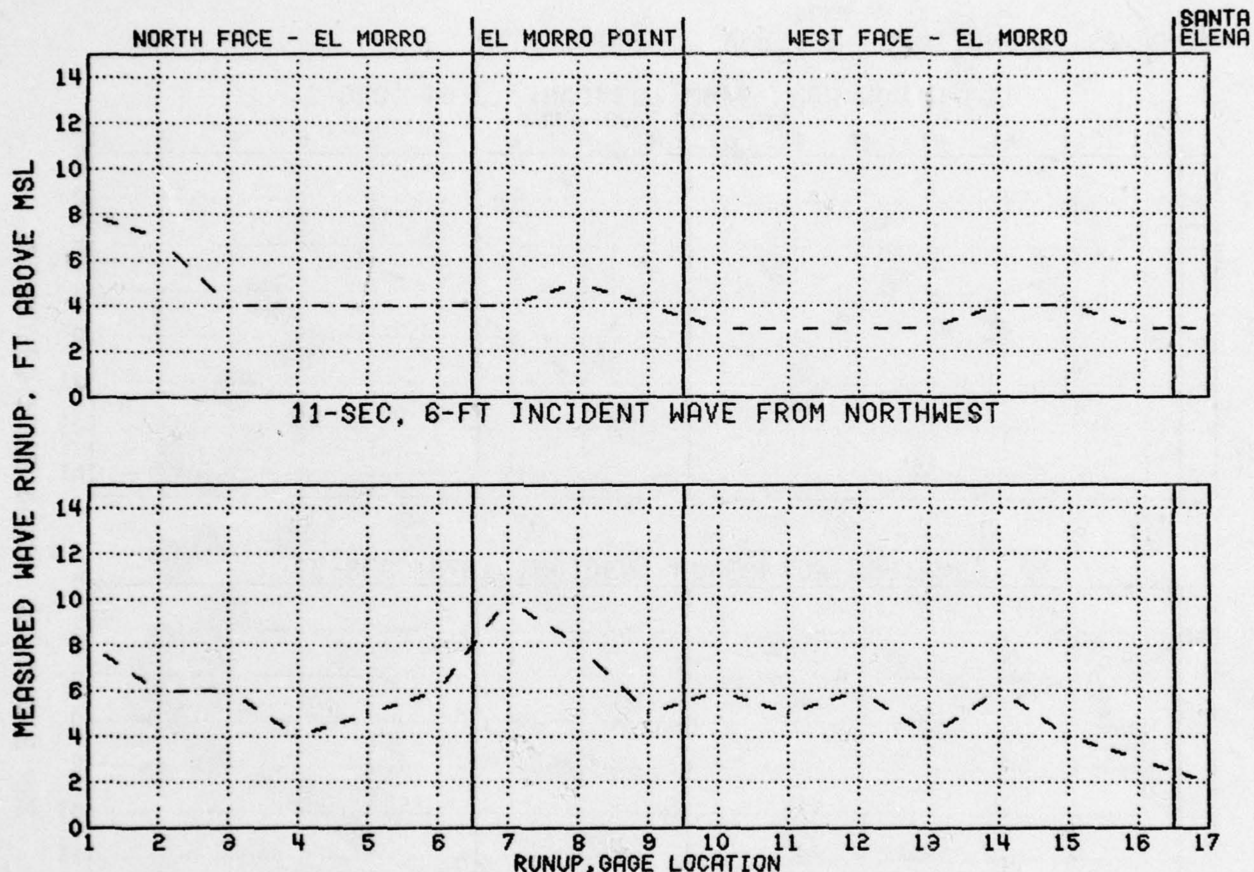
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A AND 7B



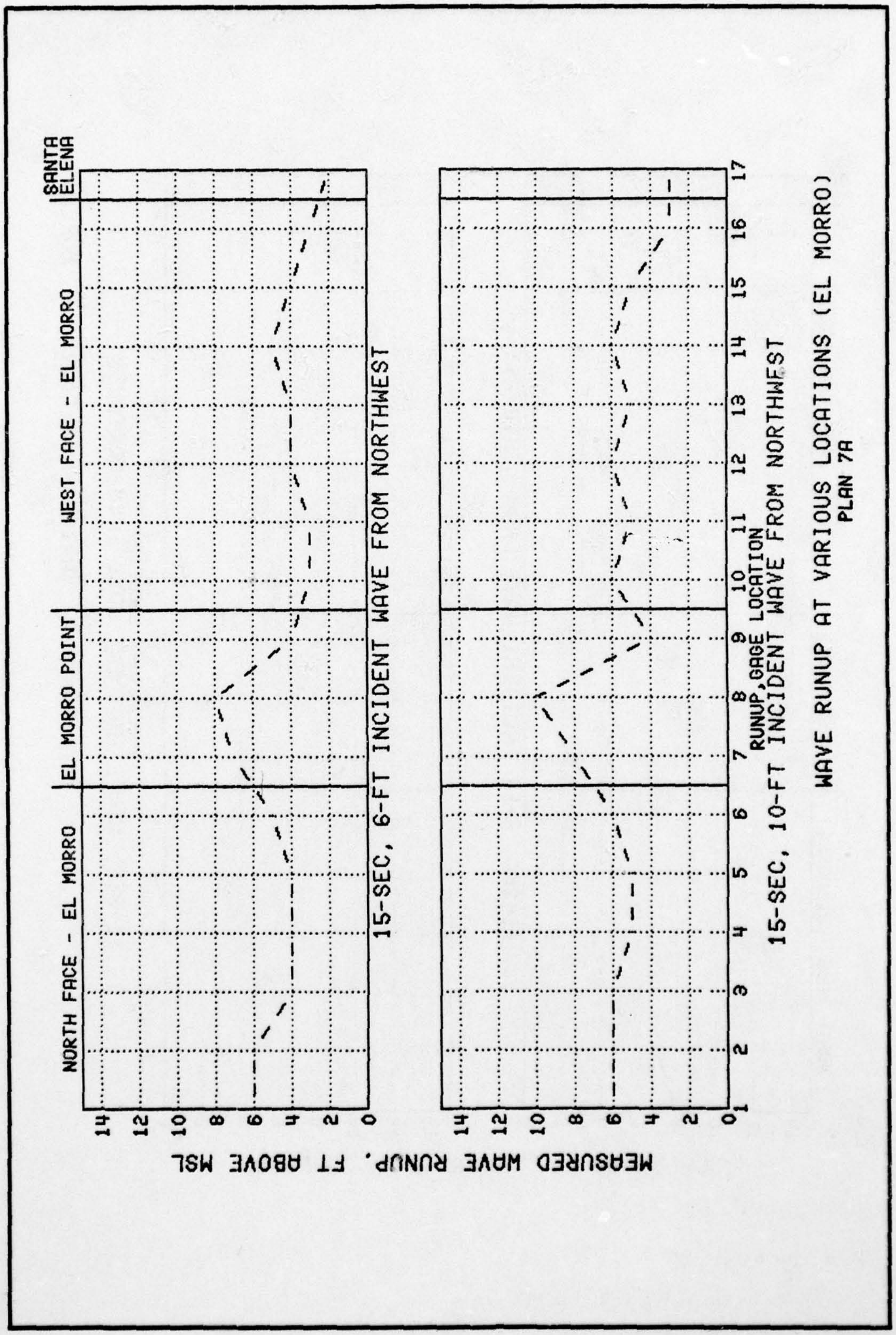
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



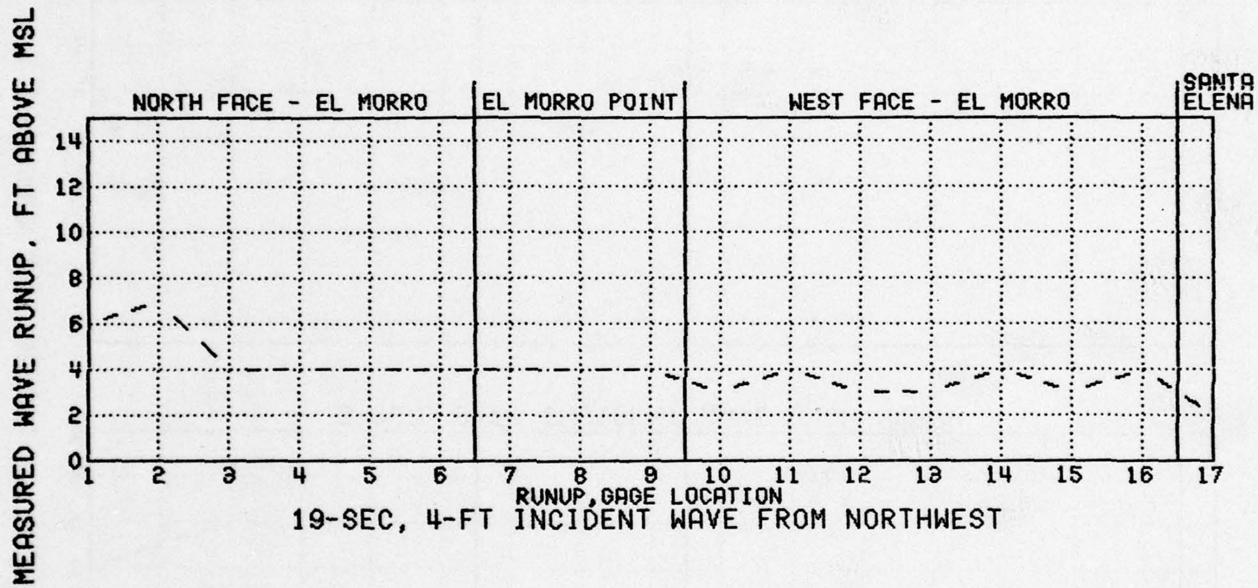
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A

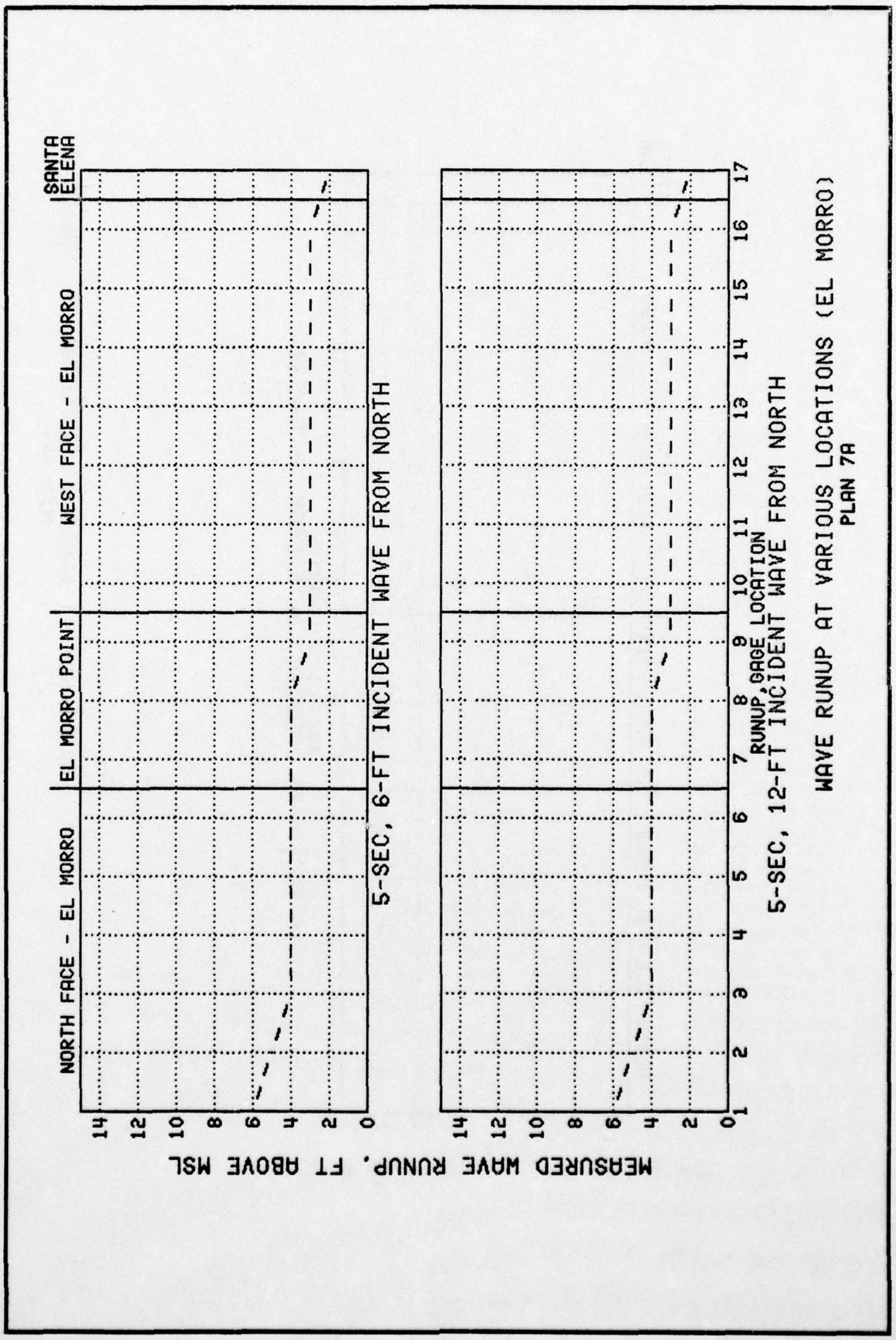


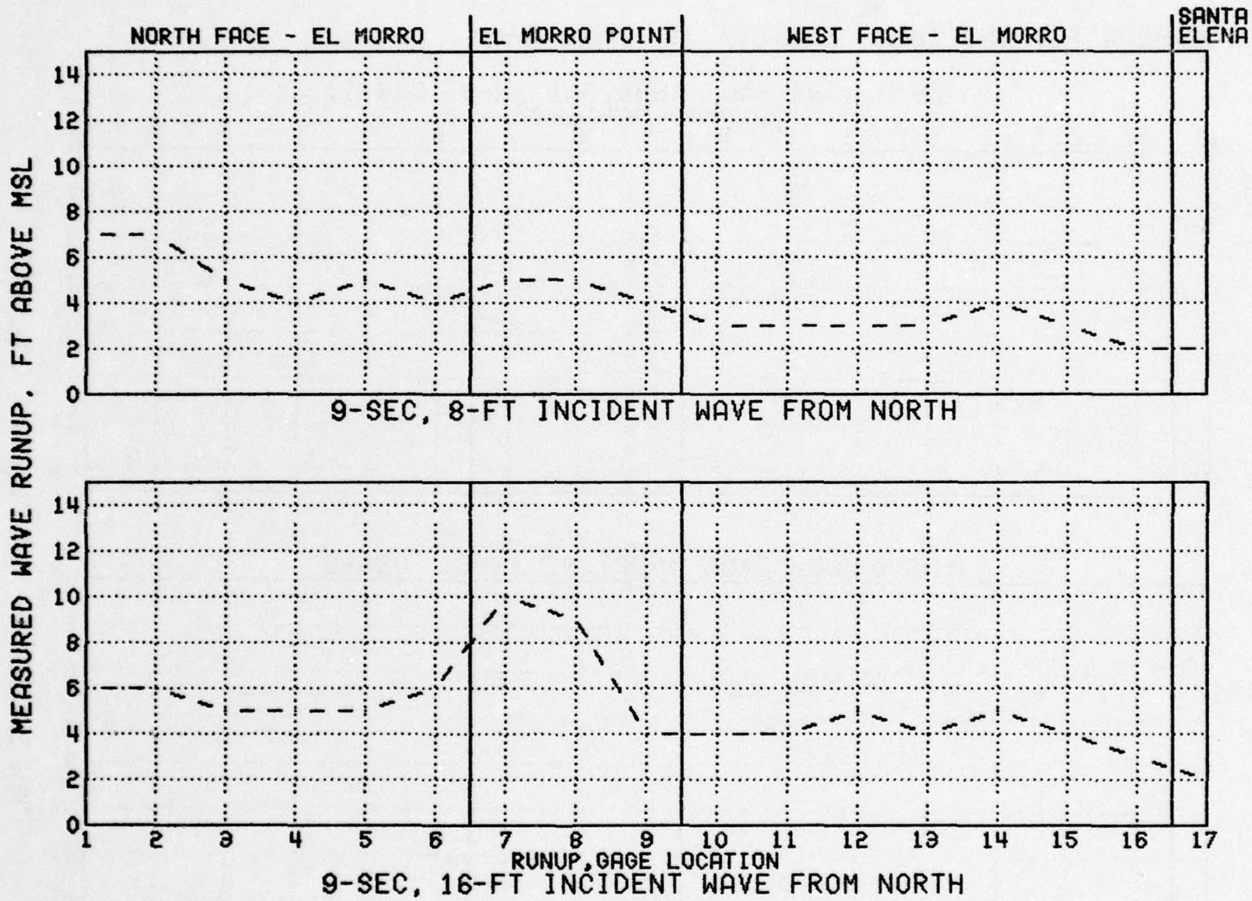
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A
15-SEC, 6-FT INCIDENT WAVE FROM NORTHWEST
15-SEC, 10-FT INCIDENT WAVE FROM NORTHWEST
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
RUNUP,GAGE LOCATION
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17



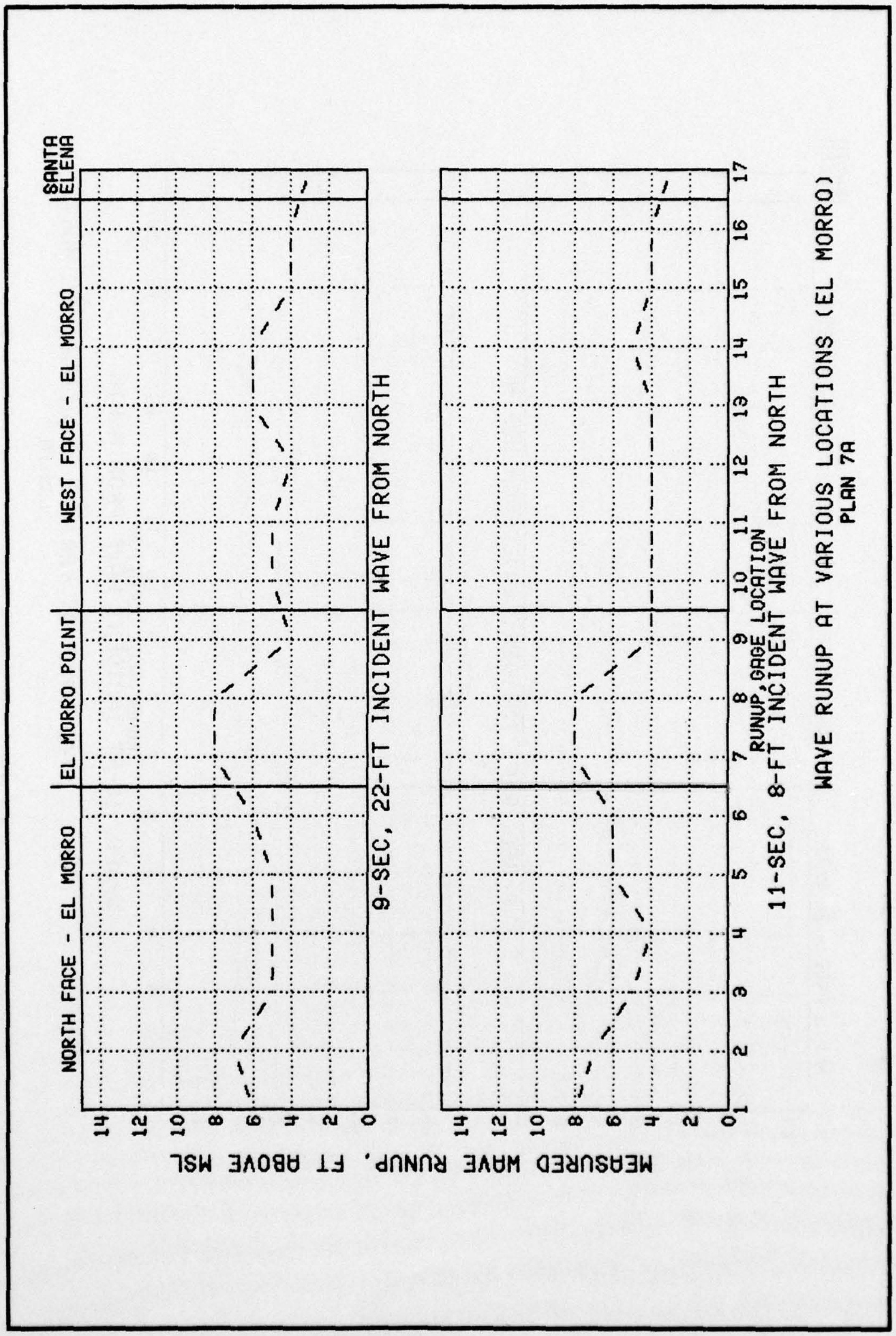
19-SEC, 4-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A

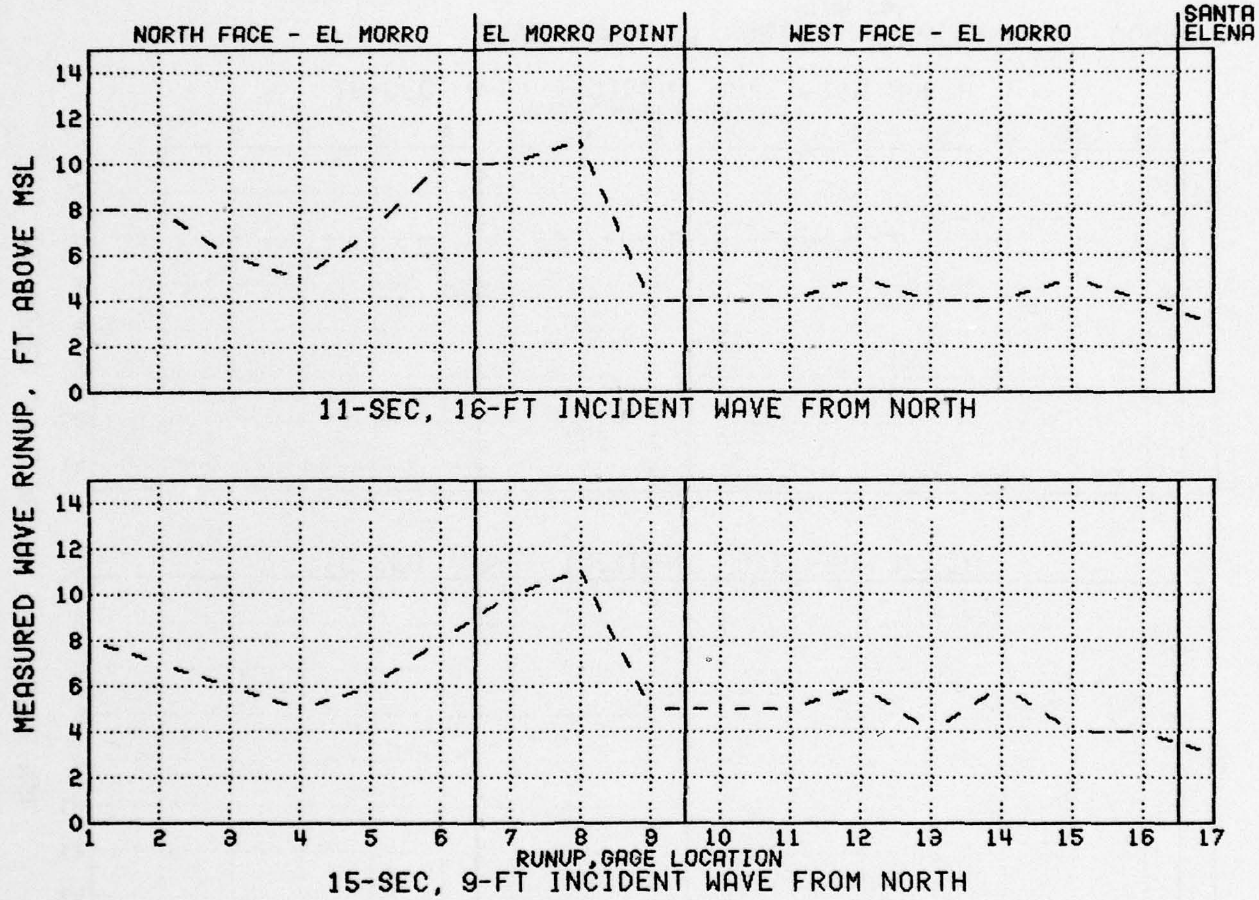

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
5-SEC, 6-FT INCIDENT WAVE FROM NORTH
5-SEC, 12-FT INCIDENT WAVE FROM NORTH
MEASURED WAVE RUNUP, FT ABOVE MSL
RUNUP GAGE LOCATION
0 2 4 6 8 10 12 14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



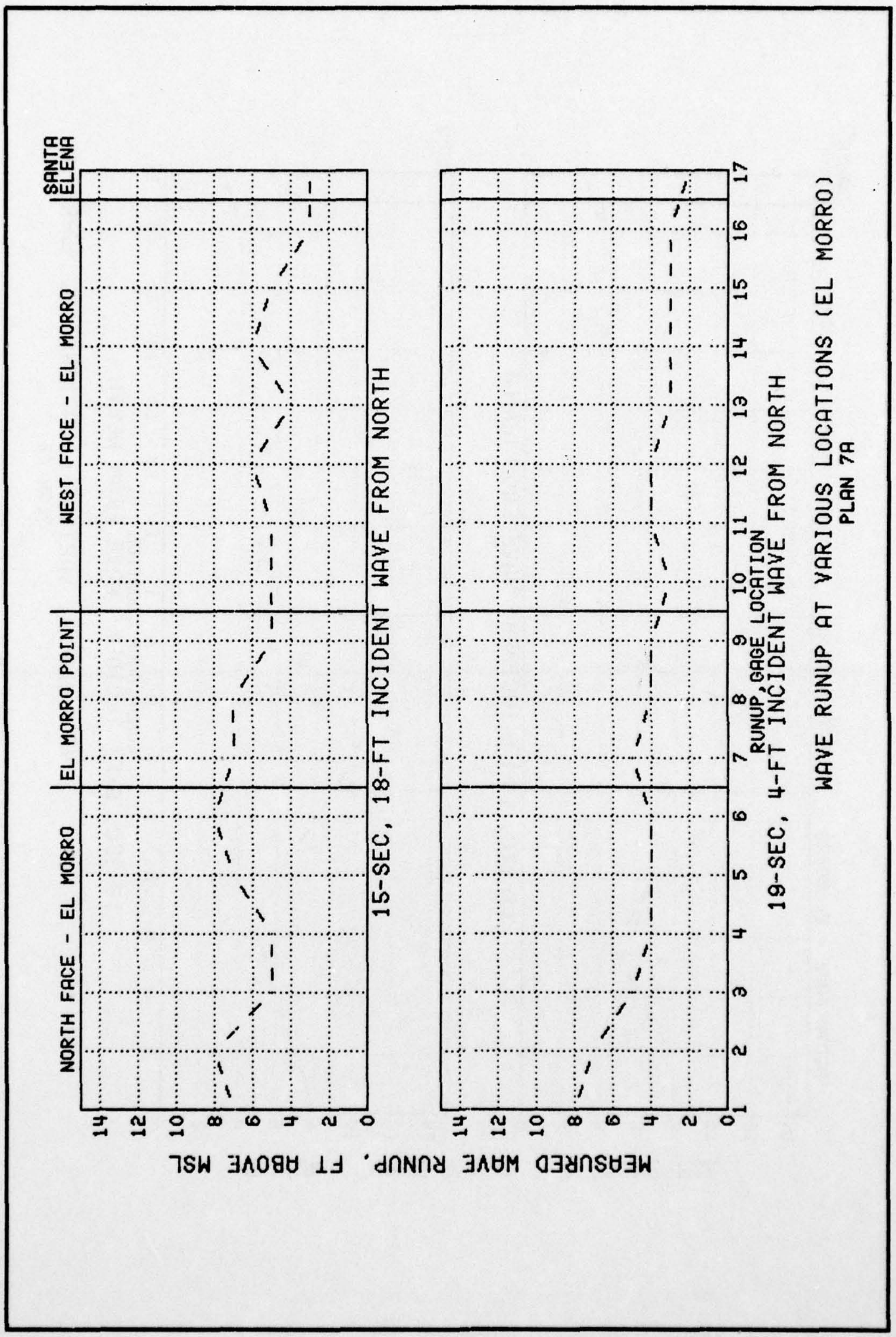
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



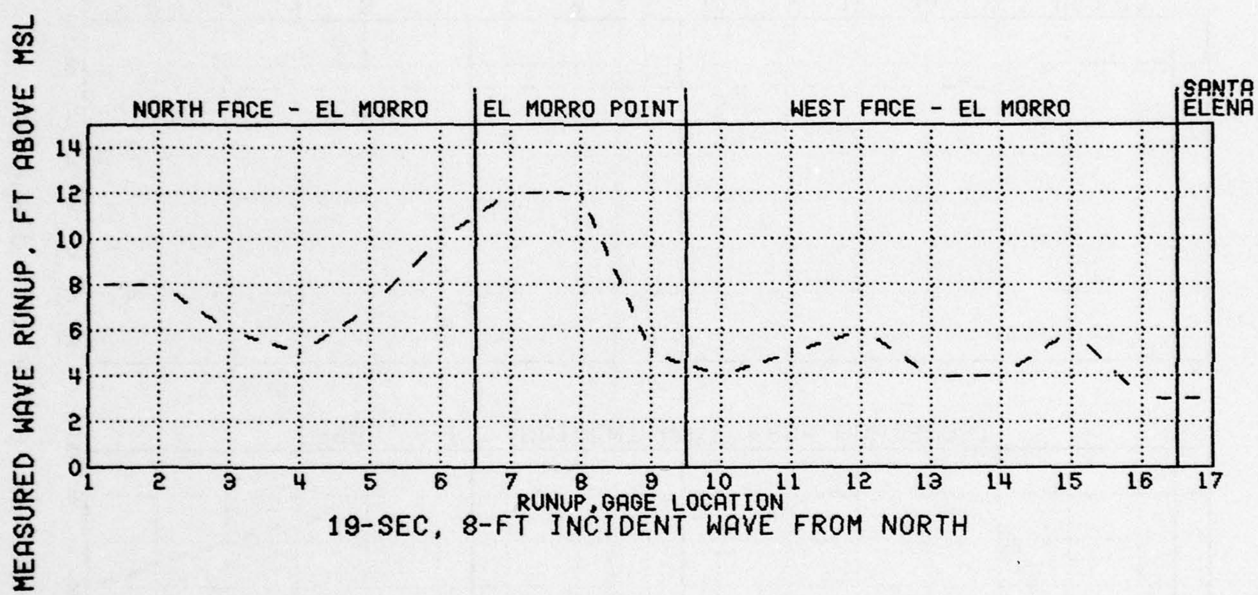
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A

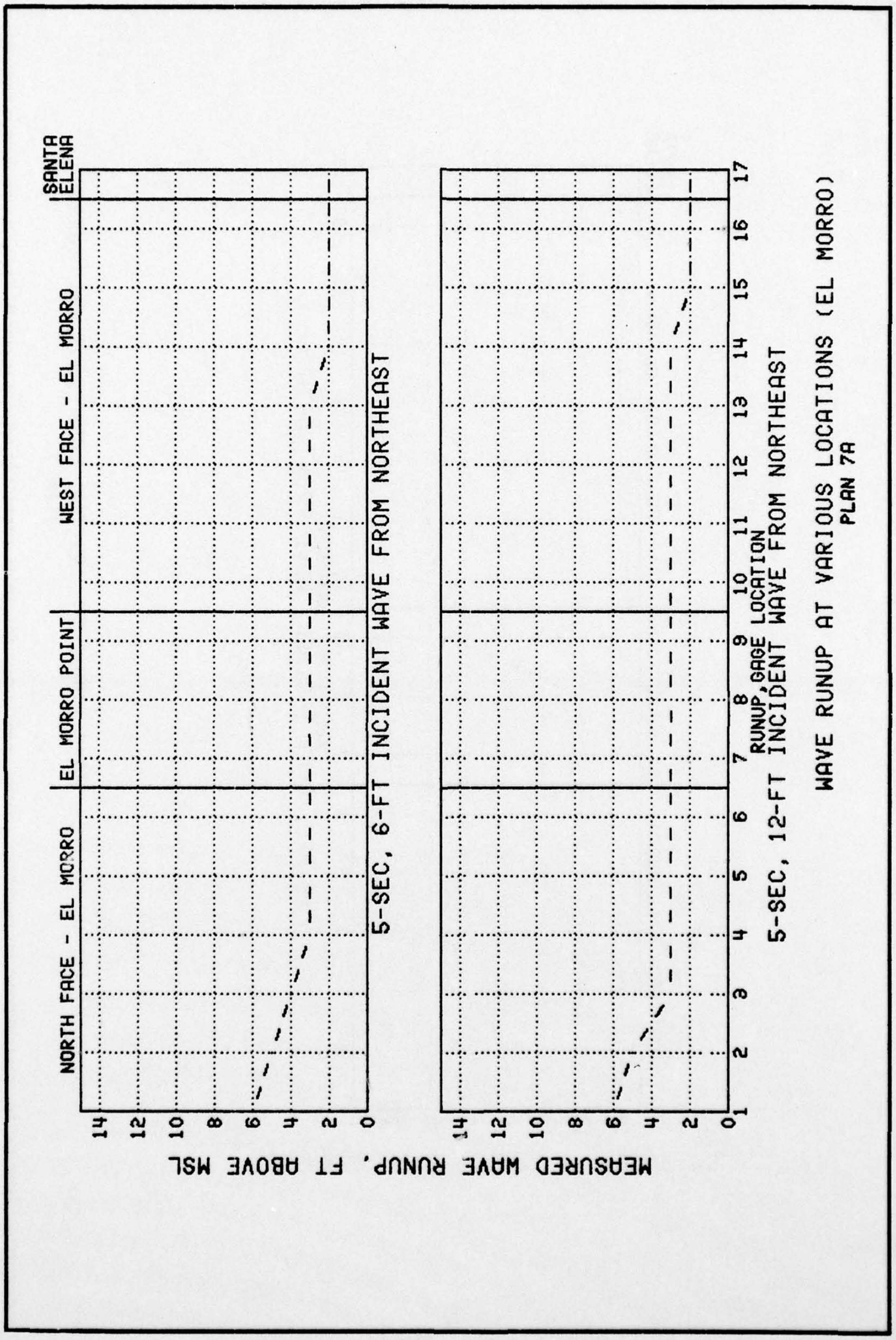


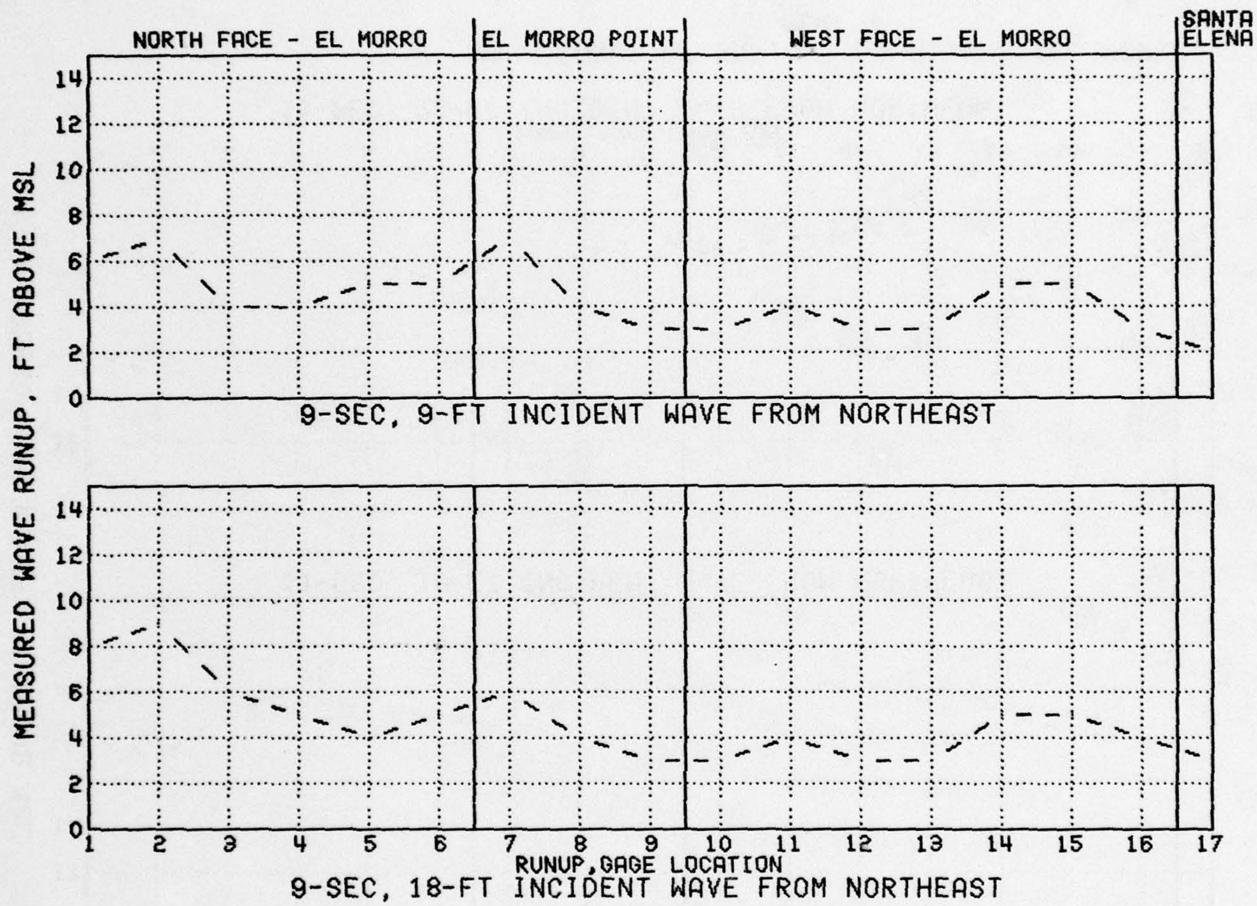
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



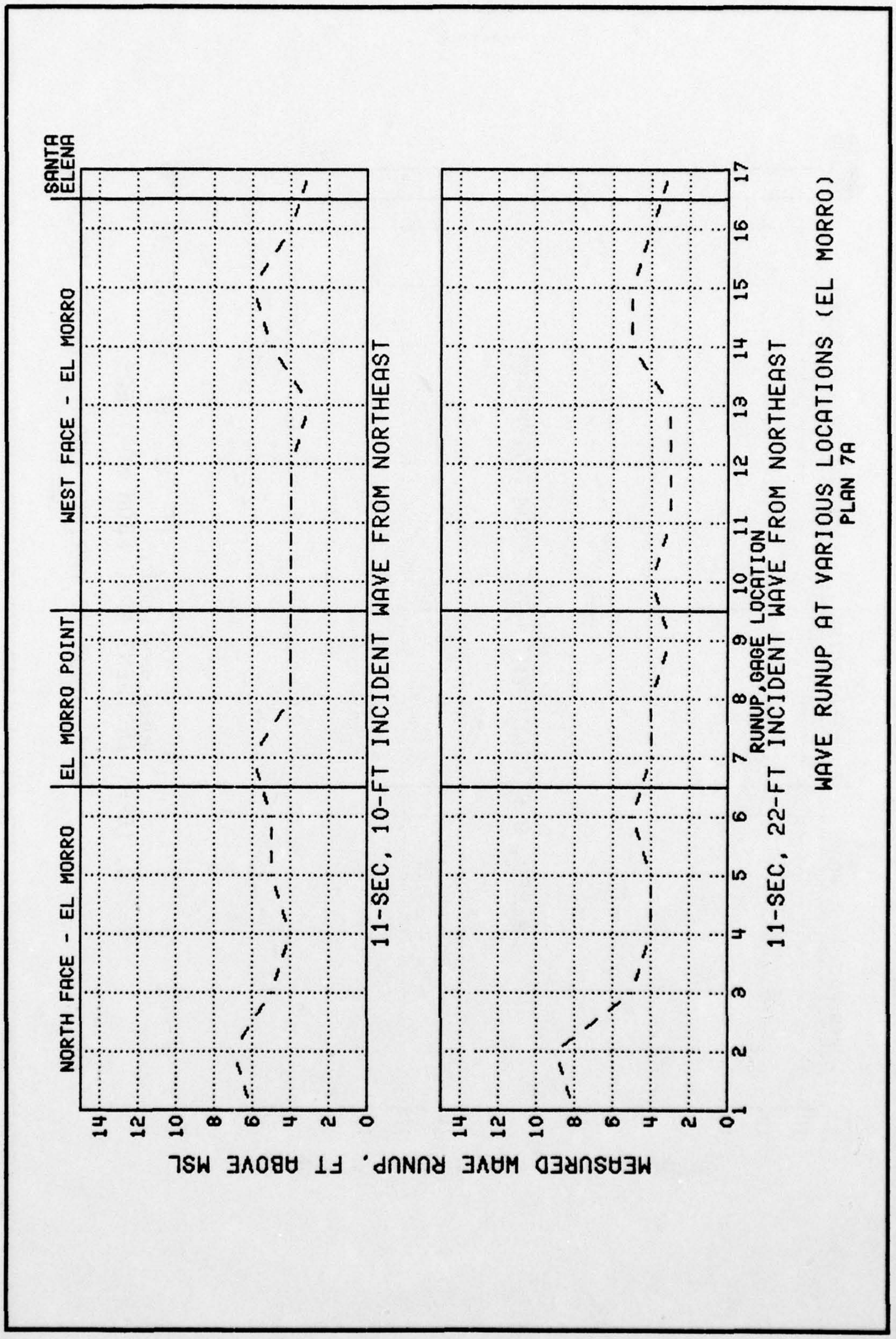
19-SEC, 8-FT INCIDENT WAVE FROM NORTH

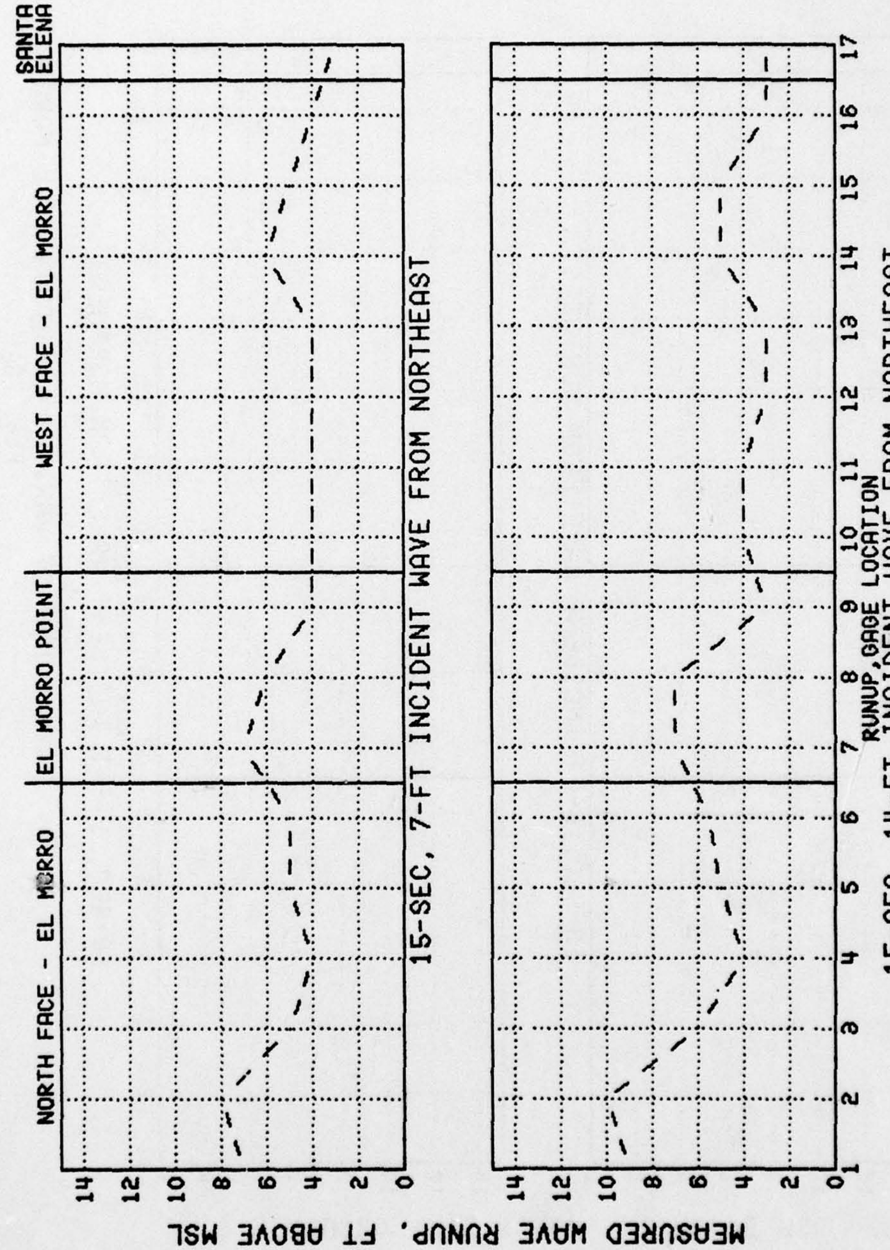
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
5-SEC, 6-FT INCIDENT WAVE FROM NORTHEAST
RUNUP, GAGE LOCATION
5-SEC, 12-FT INCIDENT WAVE FROM NORTHEAST
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A


MEASURED WAVE RUNUP, FT ABOVE MSL
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
11-SEC, 10-FT INCIDENT WAVE FROM NORTHEAST
11-SEC, 22-FT INCIDENT WAVE FROM NORTHEAST
RUNUP GAGE LOCATION
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A

AD-A075 777 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 8/3
SAN JUAN NATIONAL HISTORIC SITE, SAN JUAN, PUERTO RICO: DESIGN --ETC(U)
SEP 79 R R BOTTIN
UNCLASSIFIED WES-HL-79-15 NL

4 OF 4
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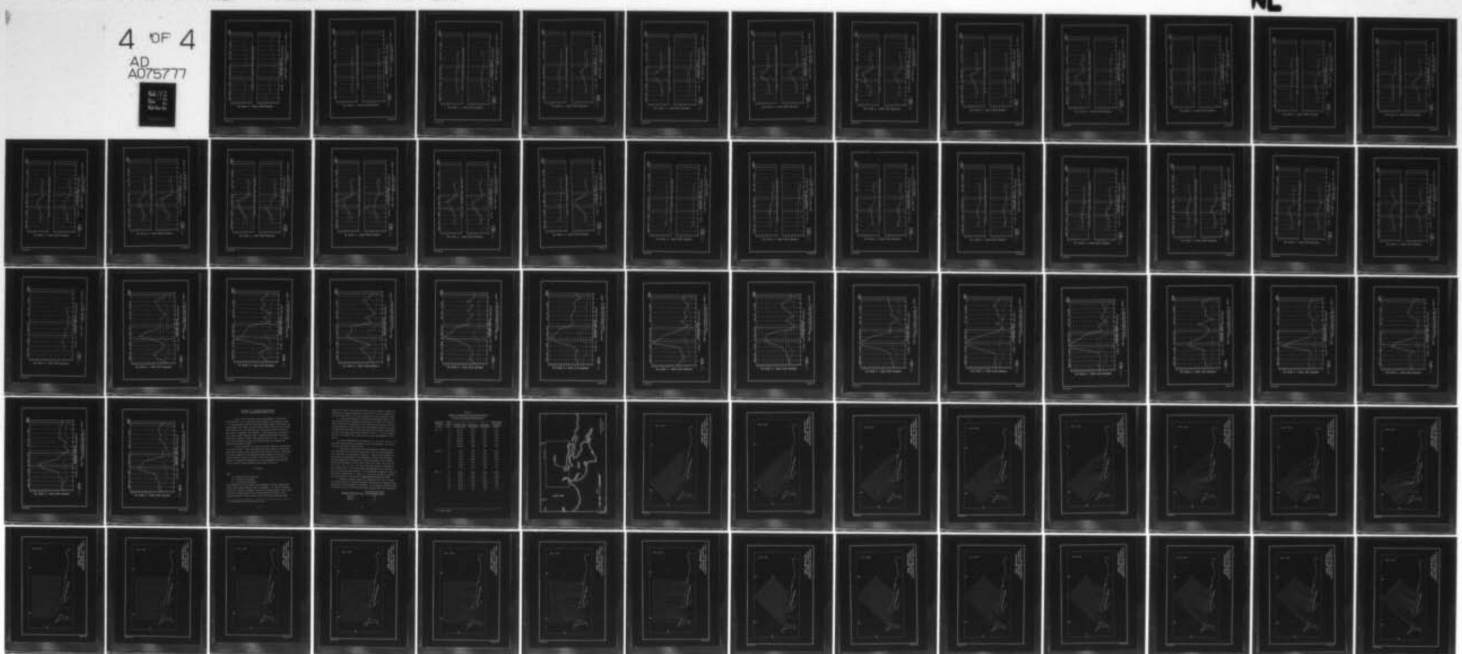

END
DATE
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DDC

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DATE
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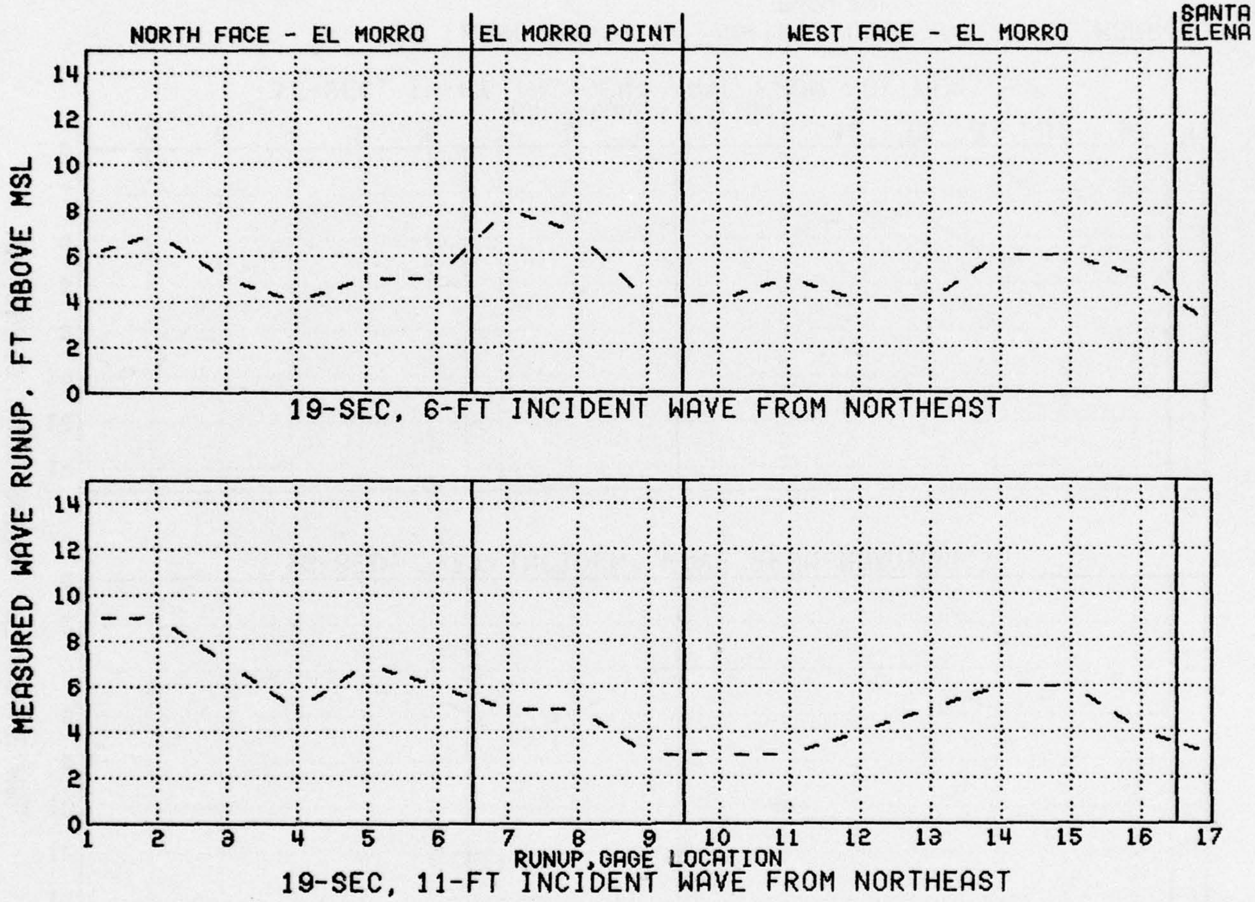
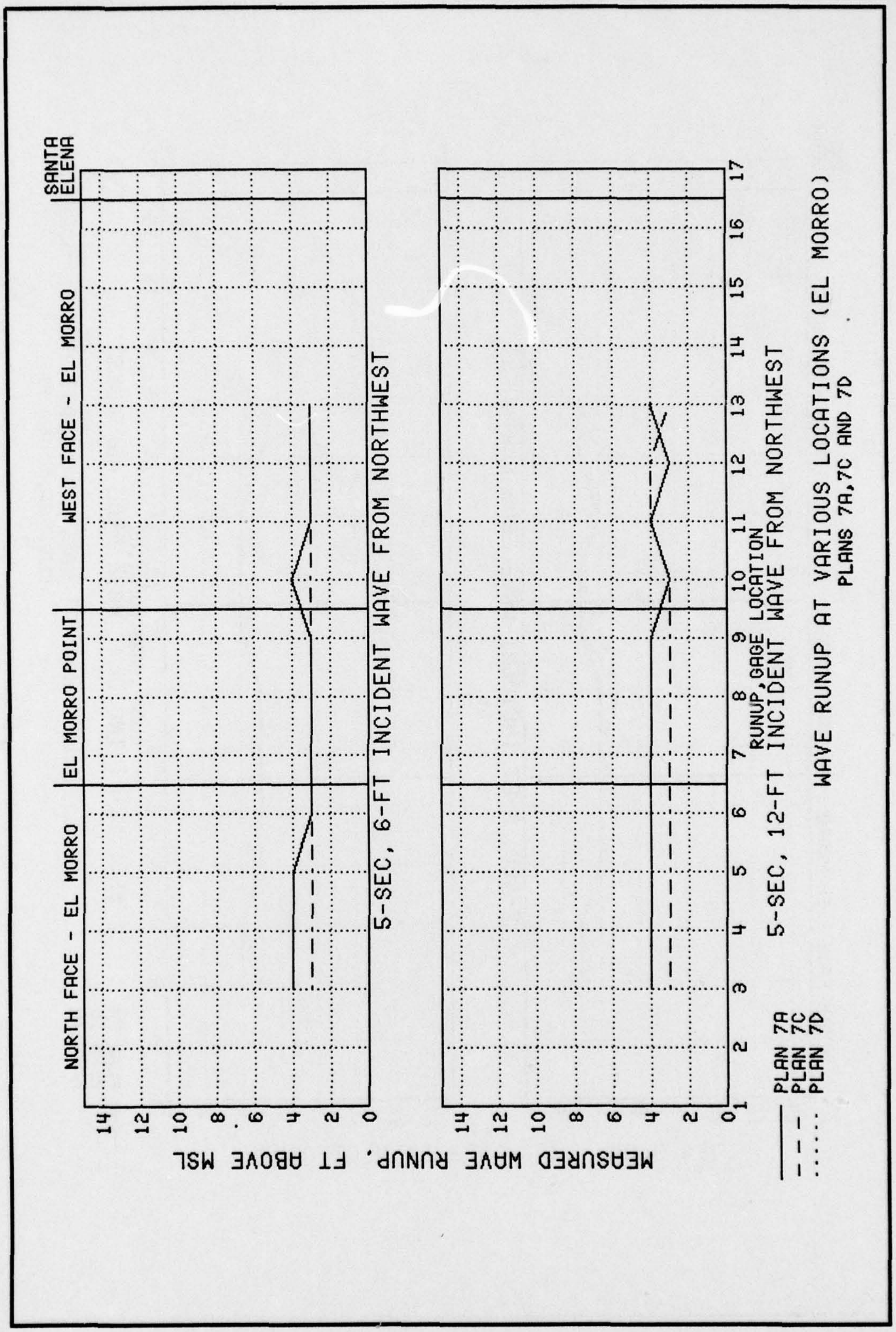
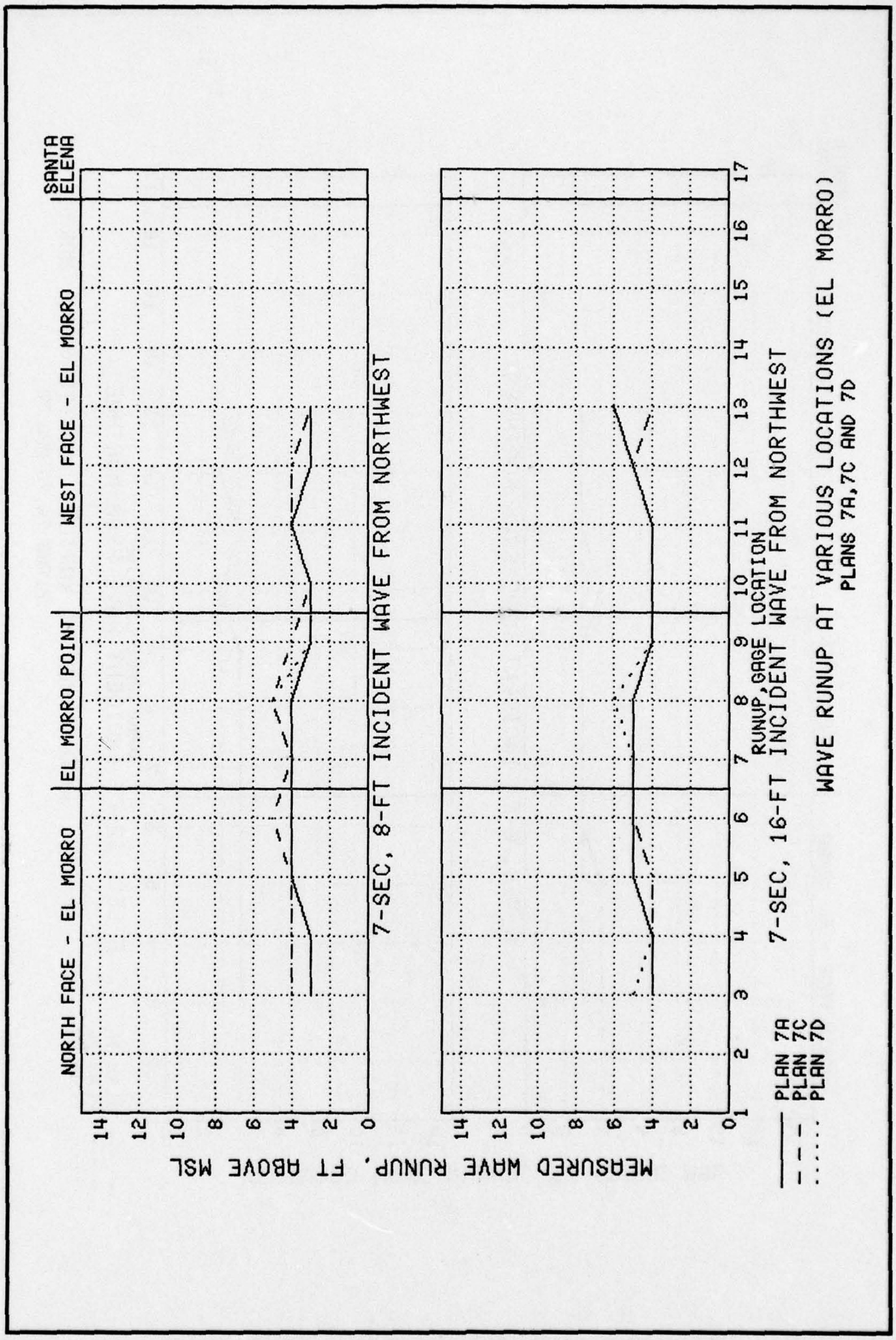
DDC

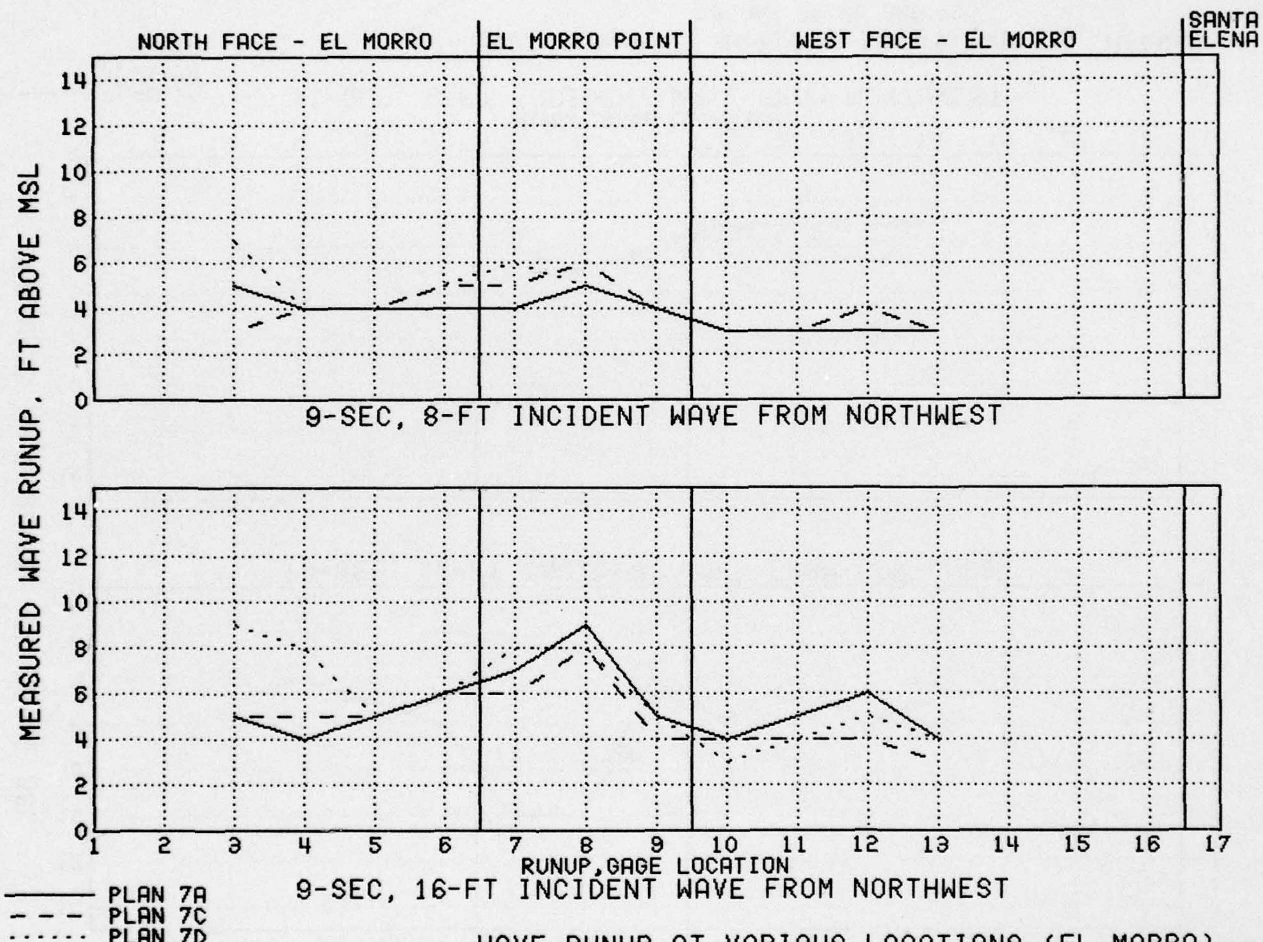


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLAN 7A

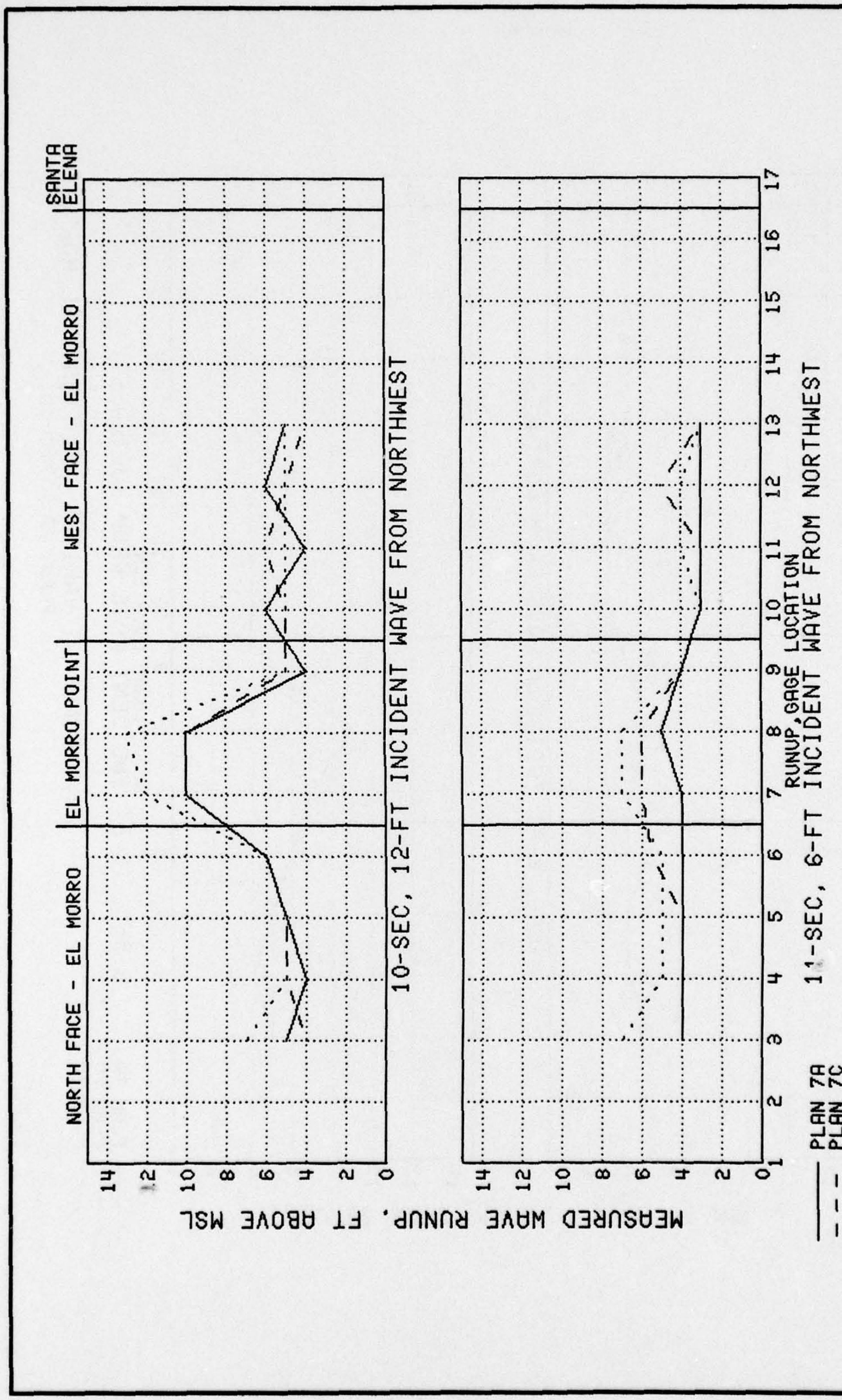

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
14
12
10
8
6
4
2
0
5-SEC, 6-FT INCIDENT WAVE FROM NORTHWEST
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP, GAGE LOCATION
5-SEC, 12-FT INCIDENT WAVE FROM NORTHWEST
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



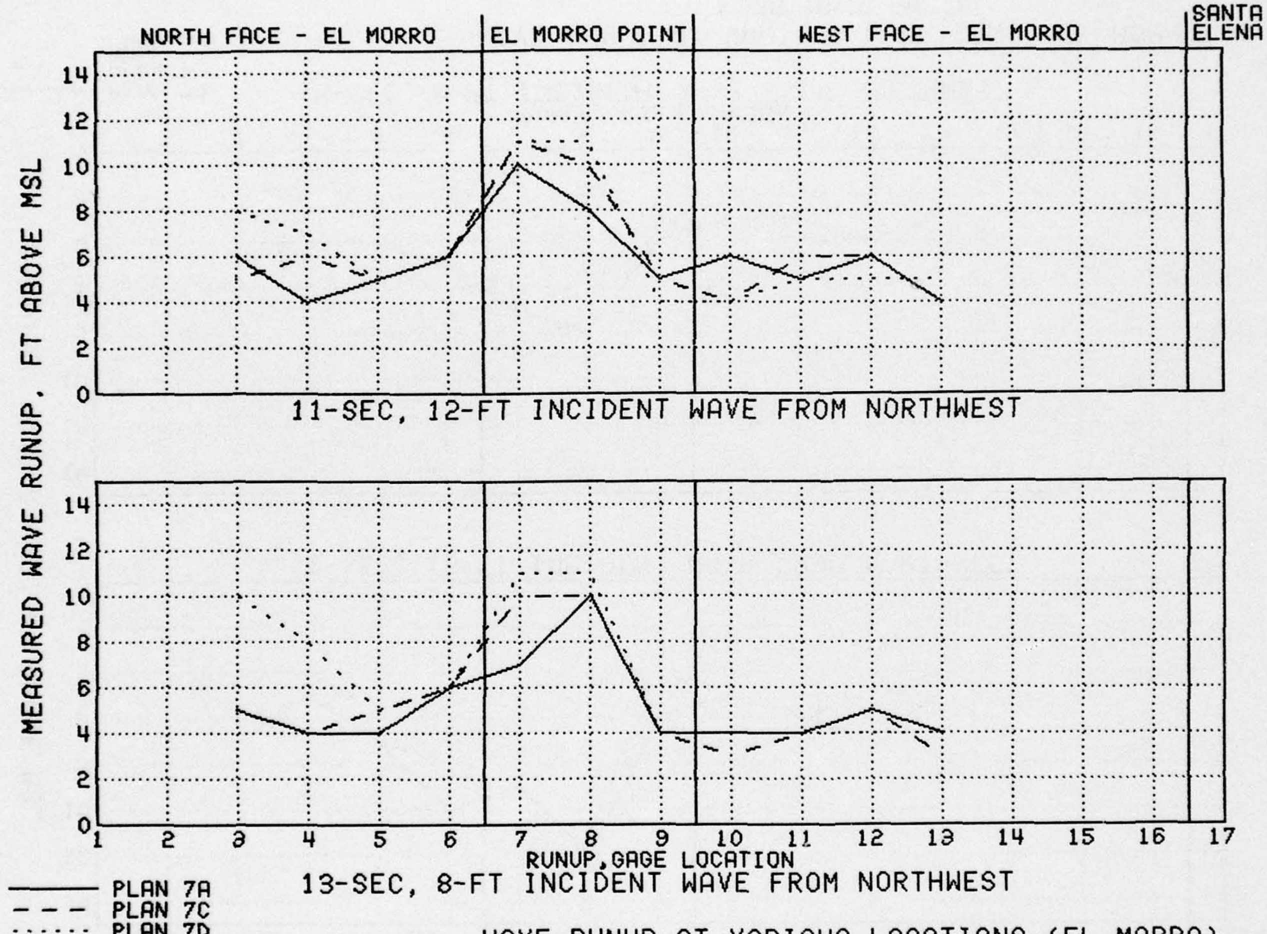
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



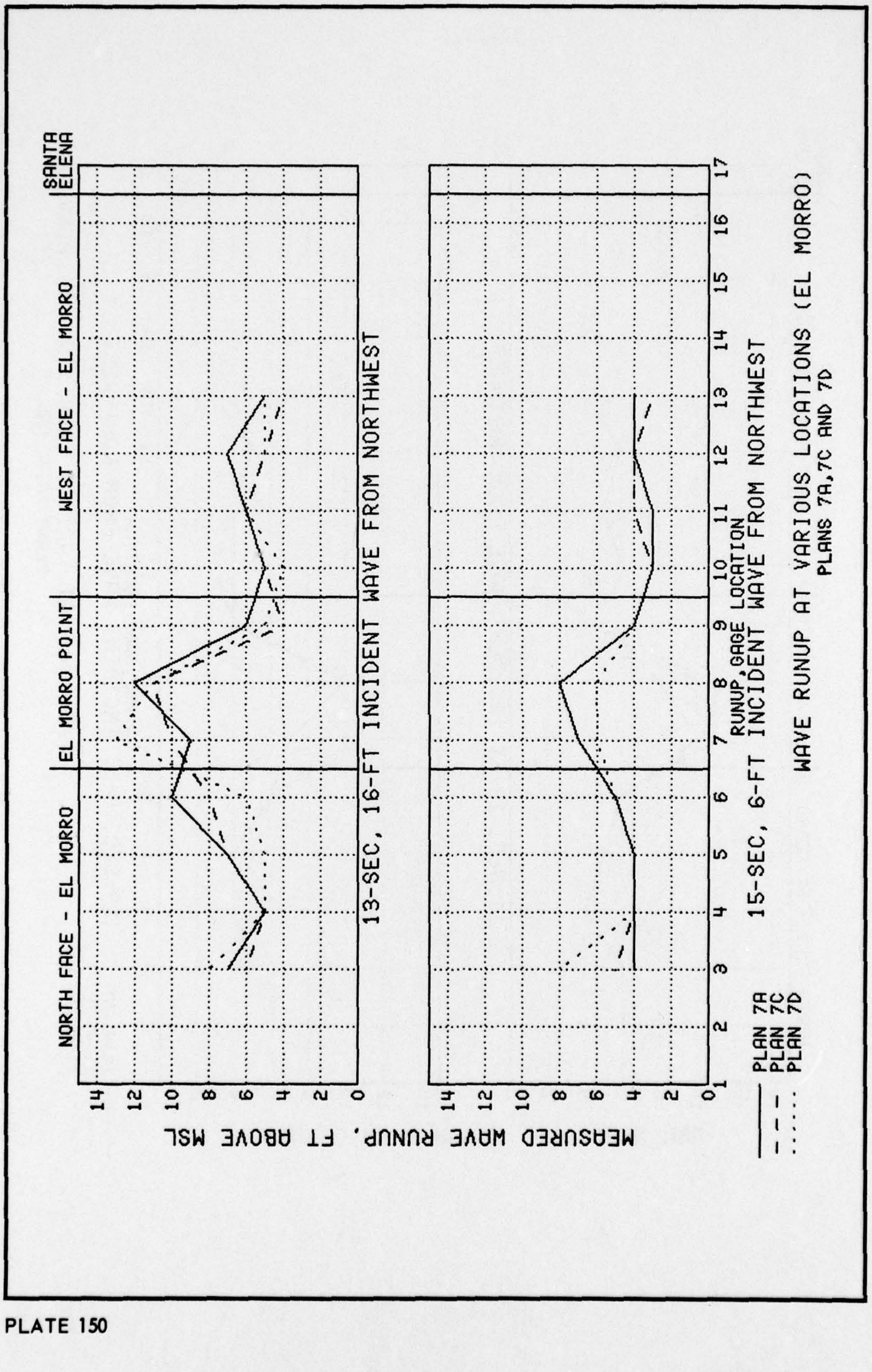
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

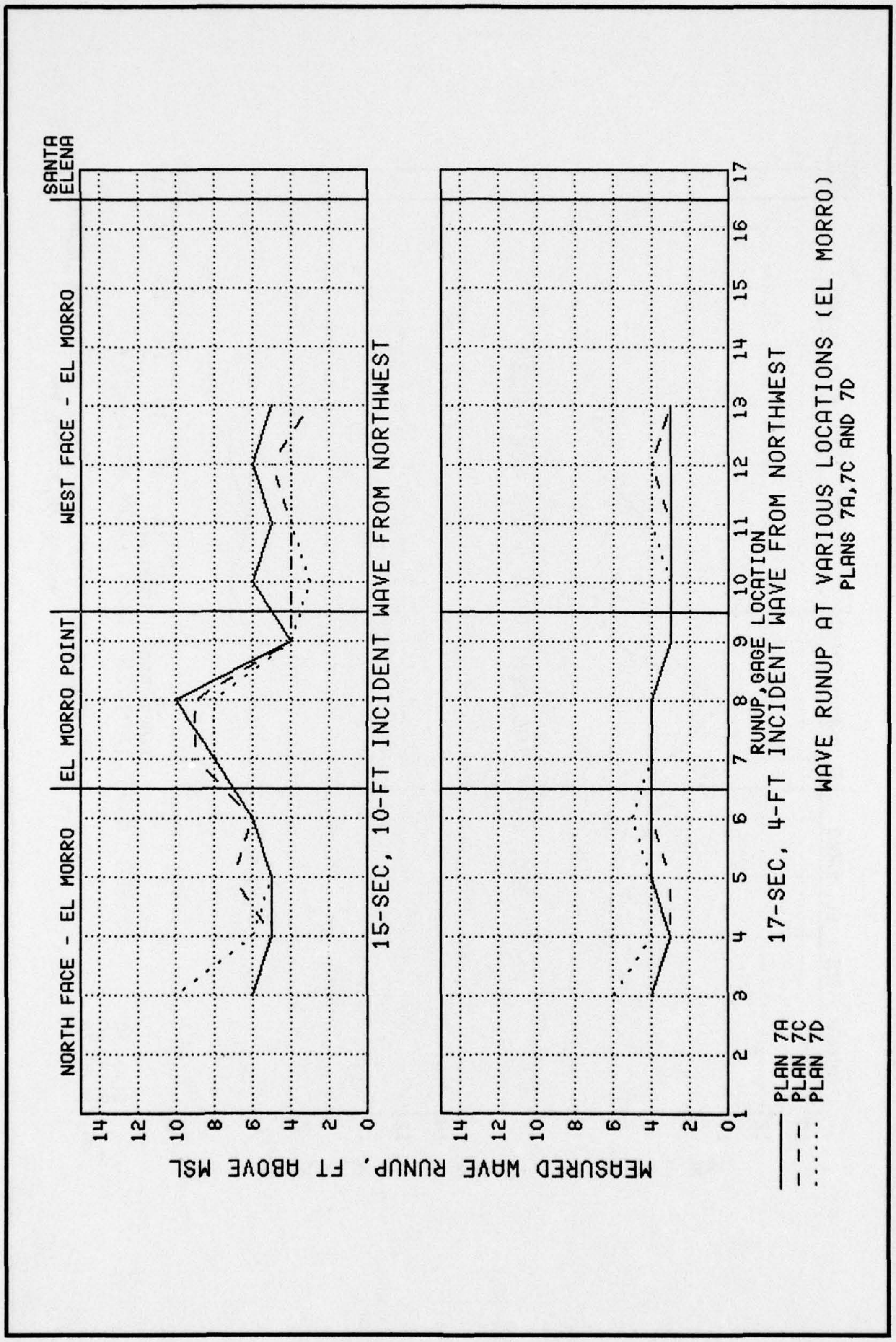


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D

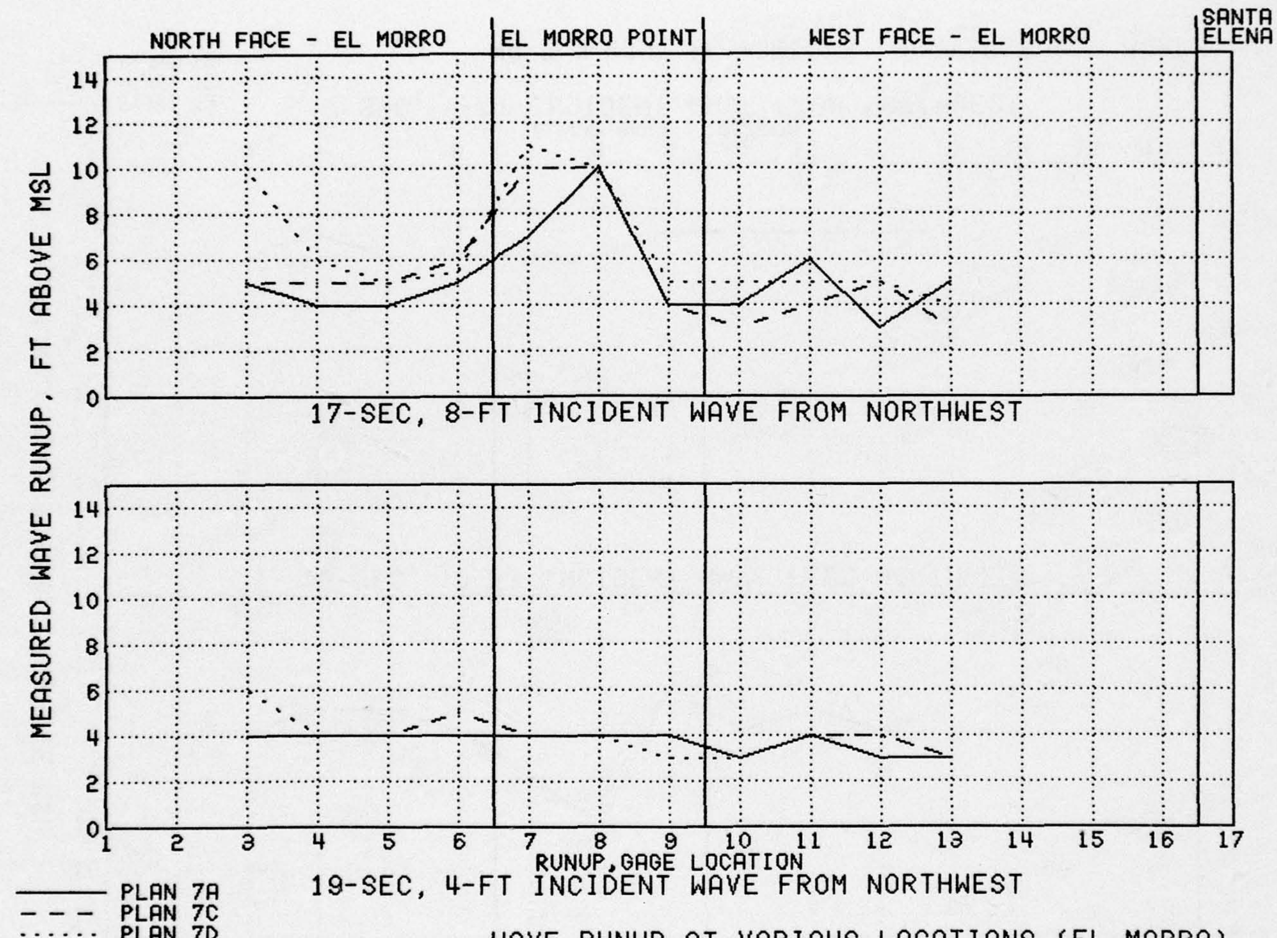


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D

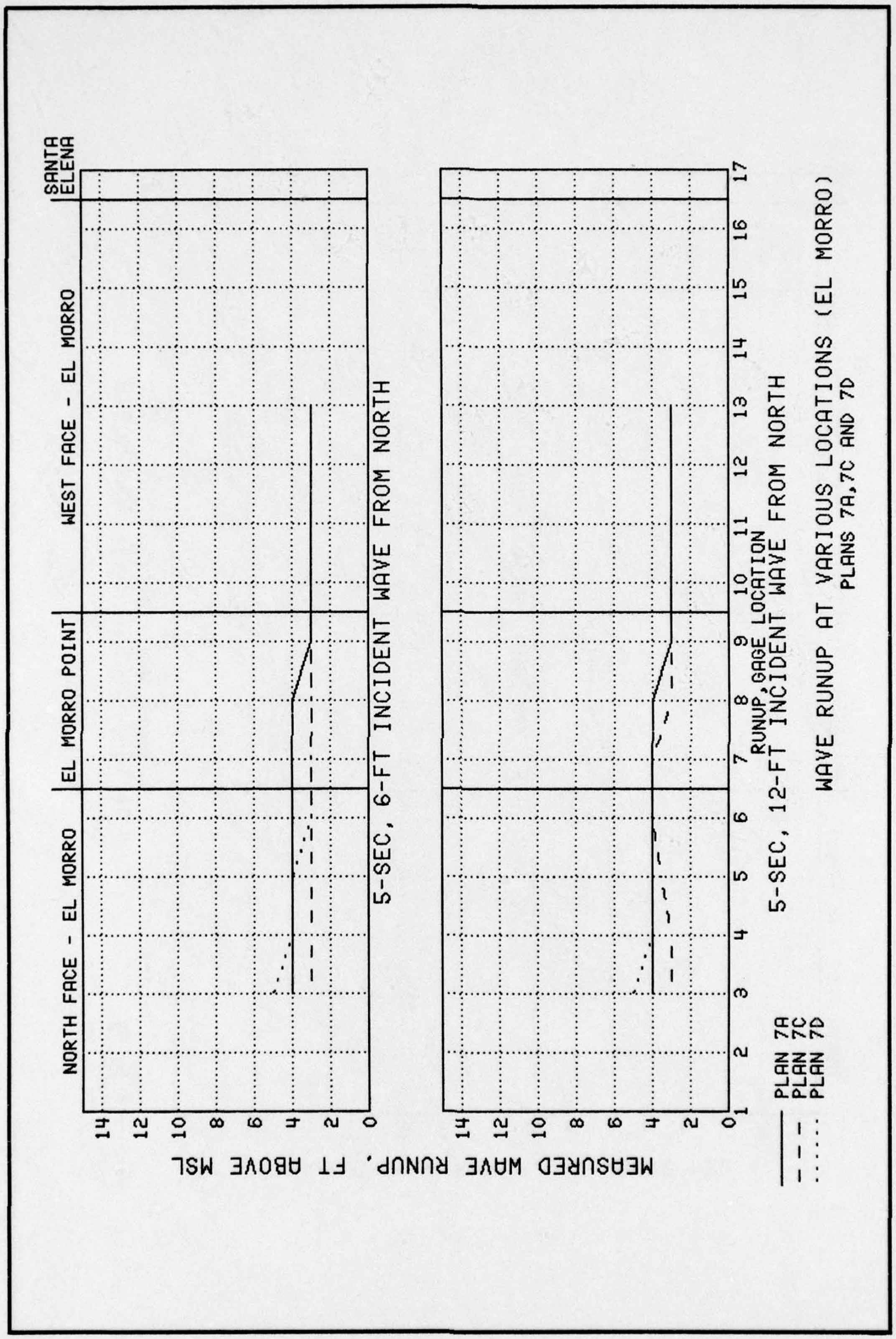

NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
13-SEC, 16-FT INCIDENT WAVE FROM NORTHWEST
RUNUP GAGE LOCATION
15-SEC, 6-FT INCIDENT WAVE FROM NORTHWEST
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D



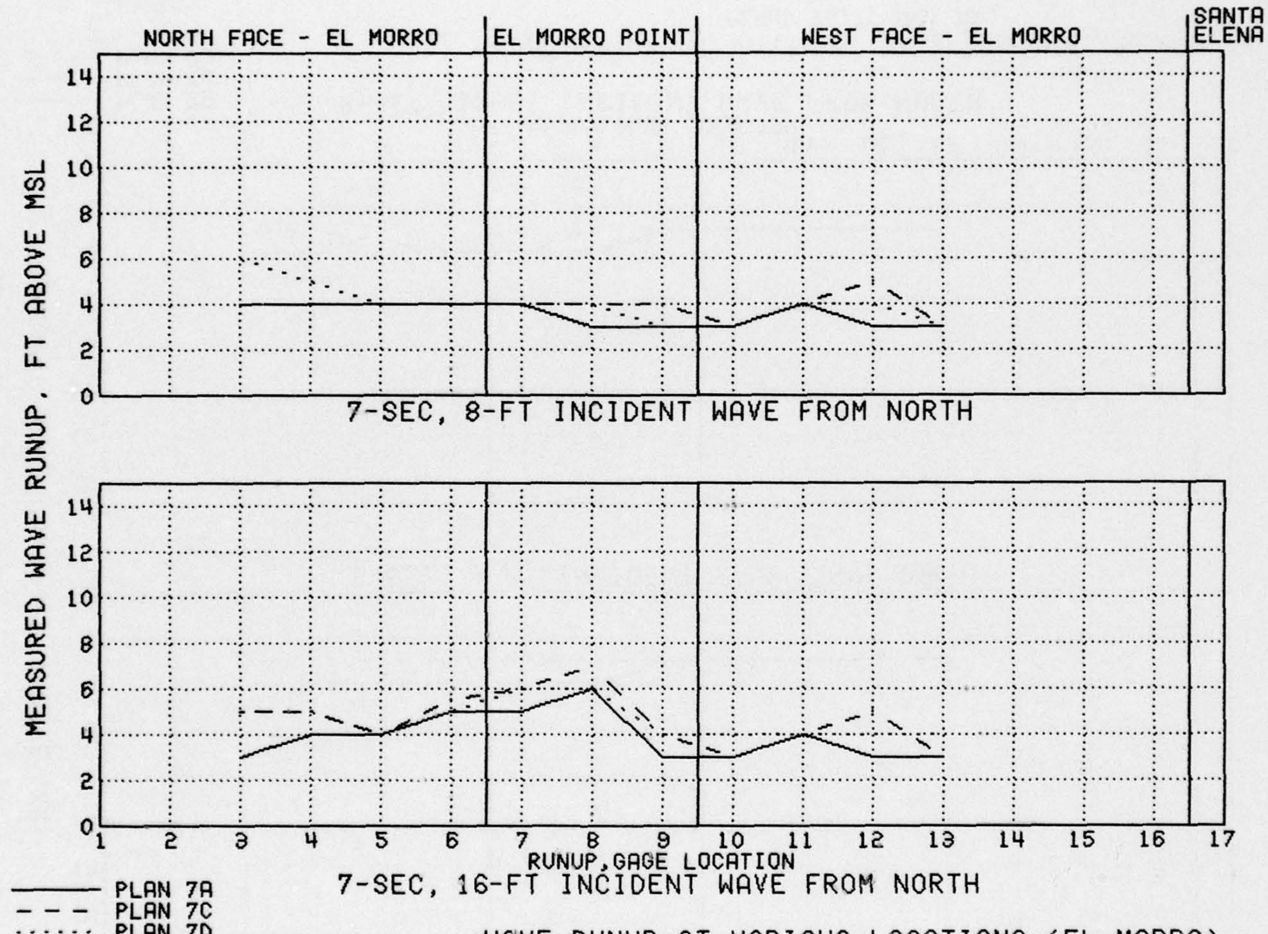
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
15-SEC, 10-FT INCIDENT WAVE FROM NORTHWEST
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
17-SEC, 4-FT INCIDENT WAVE FROM NORTHWEST
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



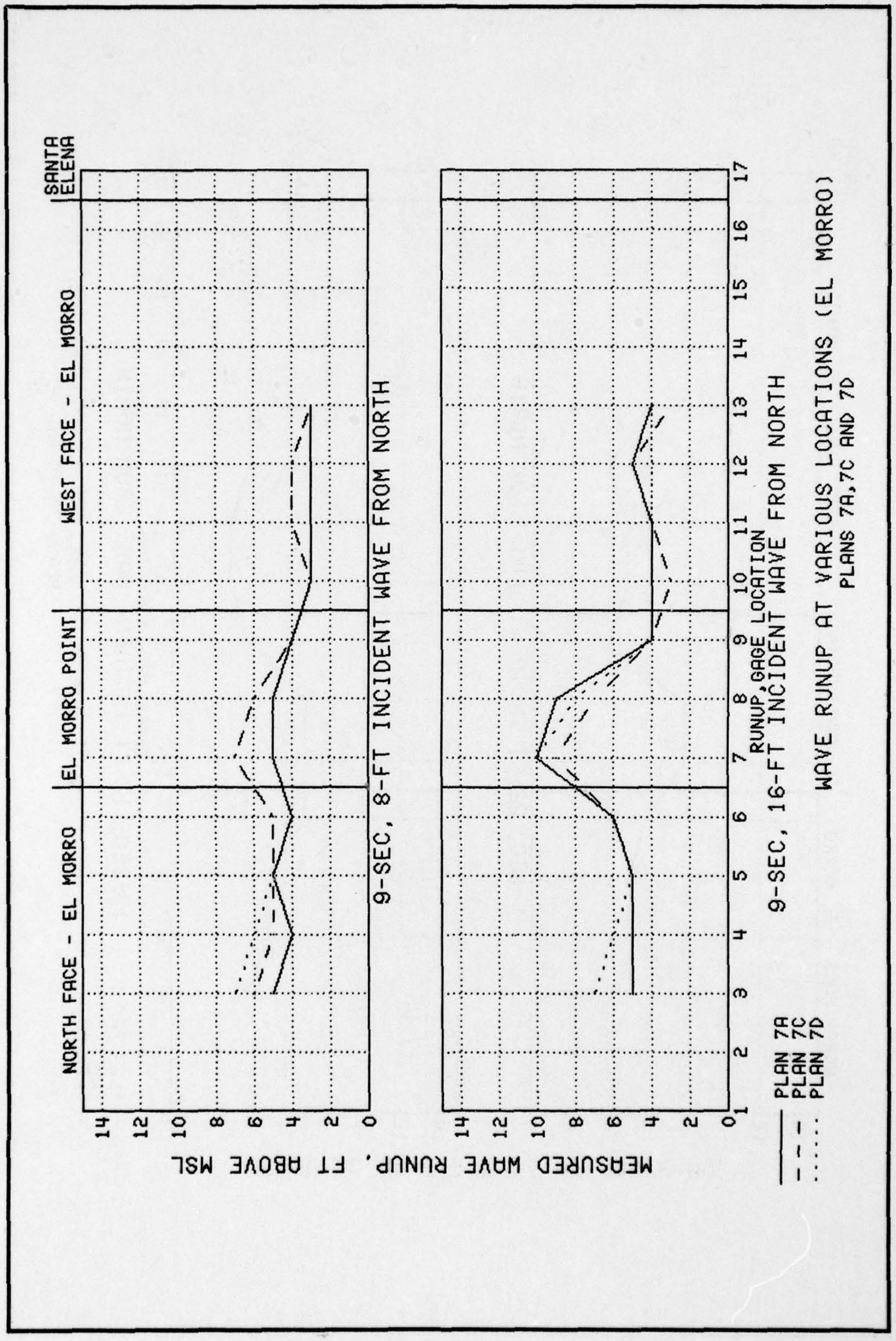
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D



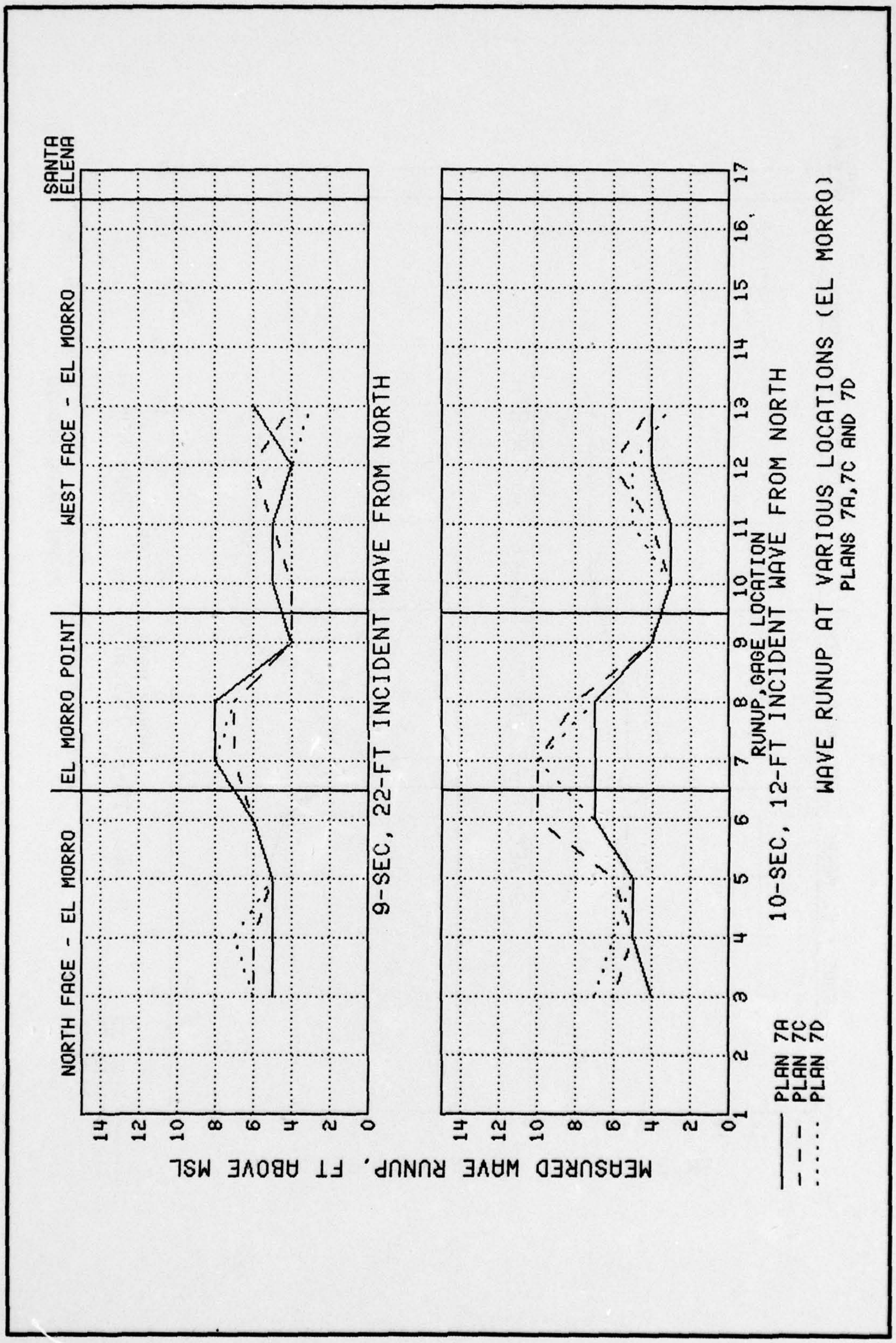
MEASURED WAVE RUNUP, FT ABOVE MSL
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
0 2 4 6 8 10 12 14
5-SEC, 6-FT INCIDENT WAVE FROM NORTH
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
RUNUP GAGE LOCATION
5-SEC, 12-FT INCIDENT WAVE FROM NORTH
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



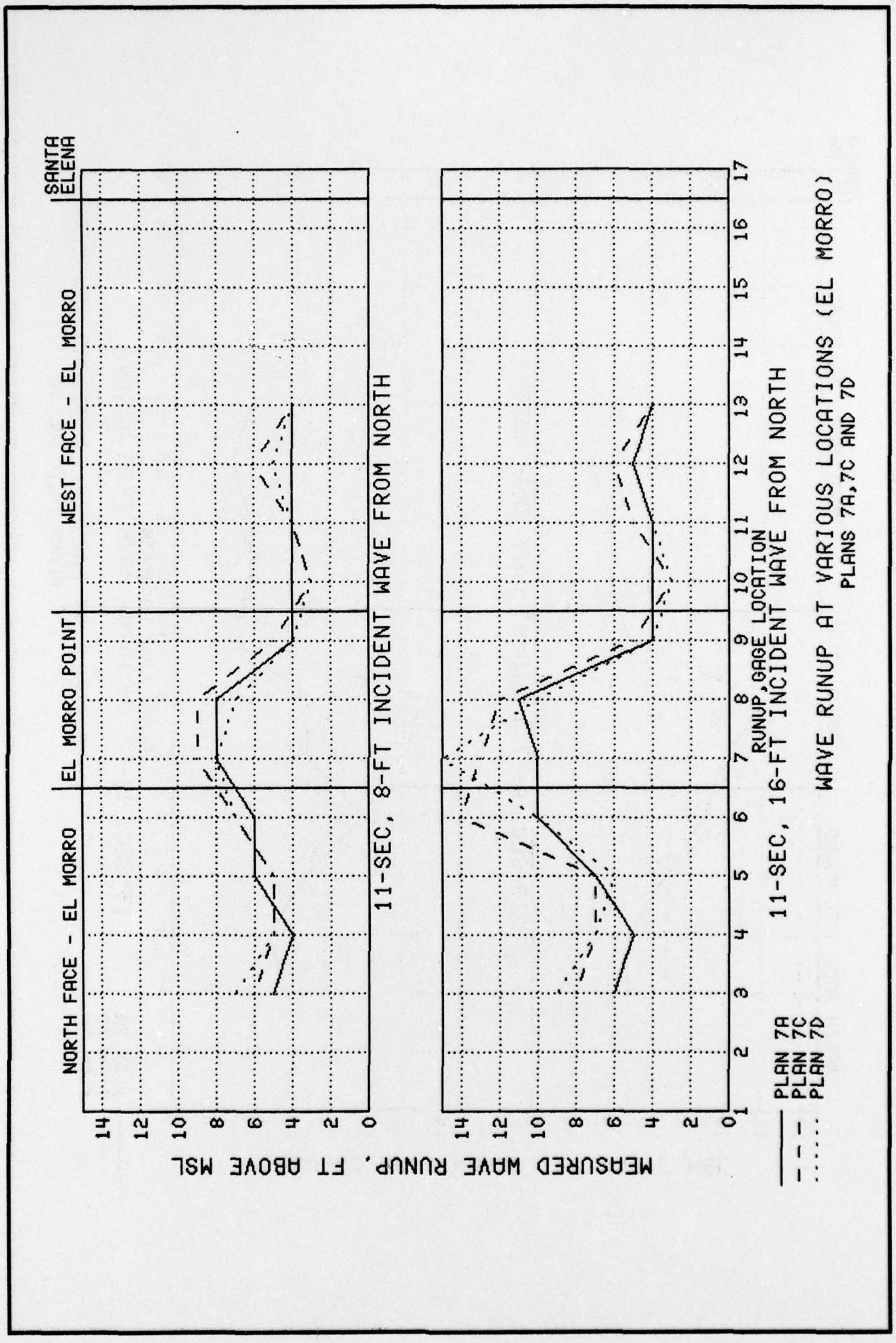
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

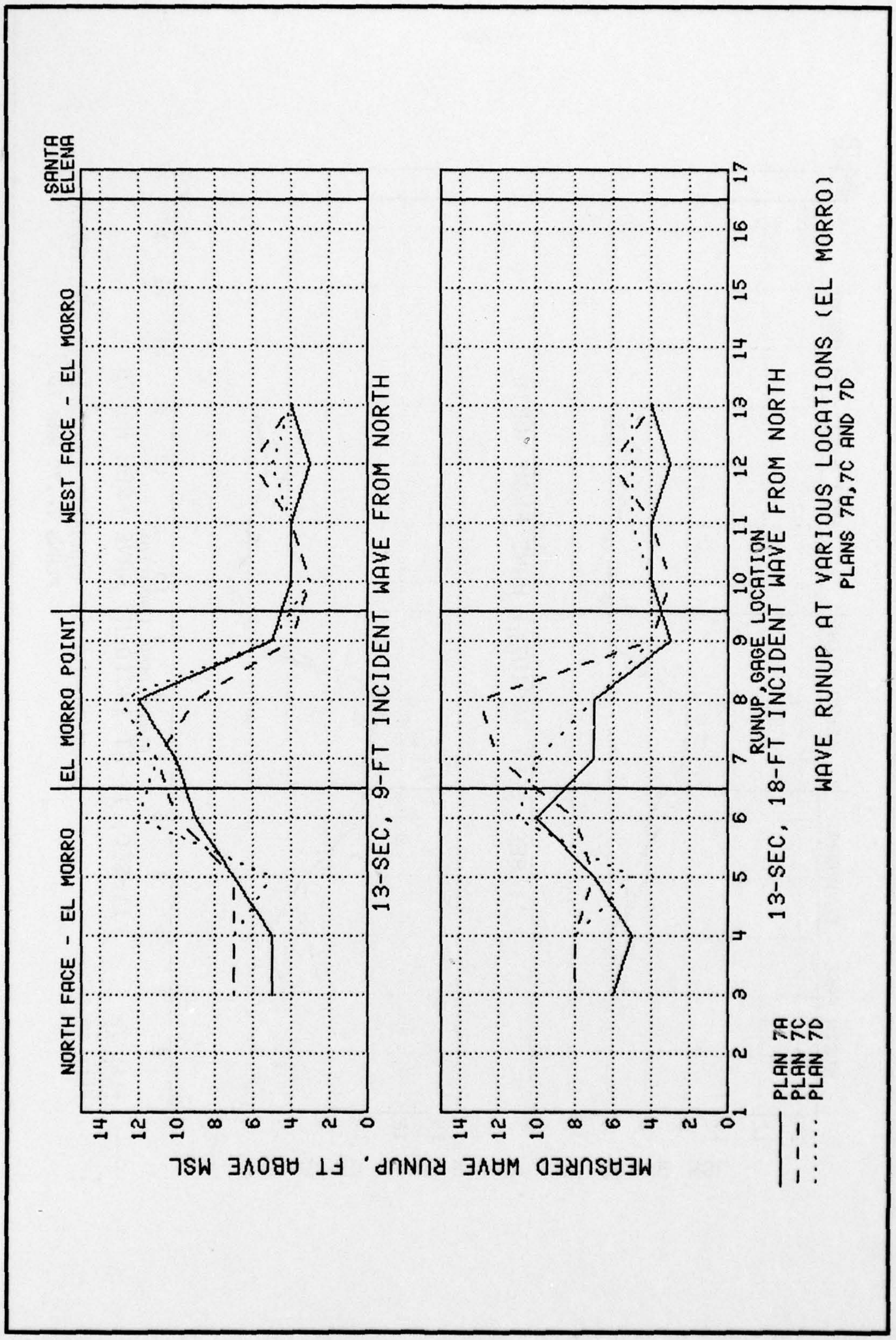


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D



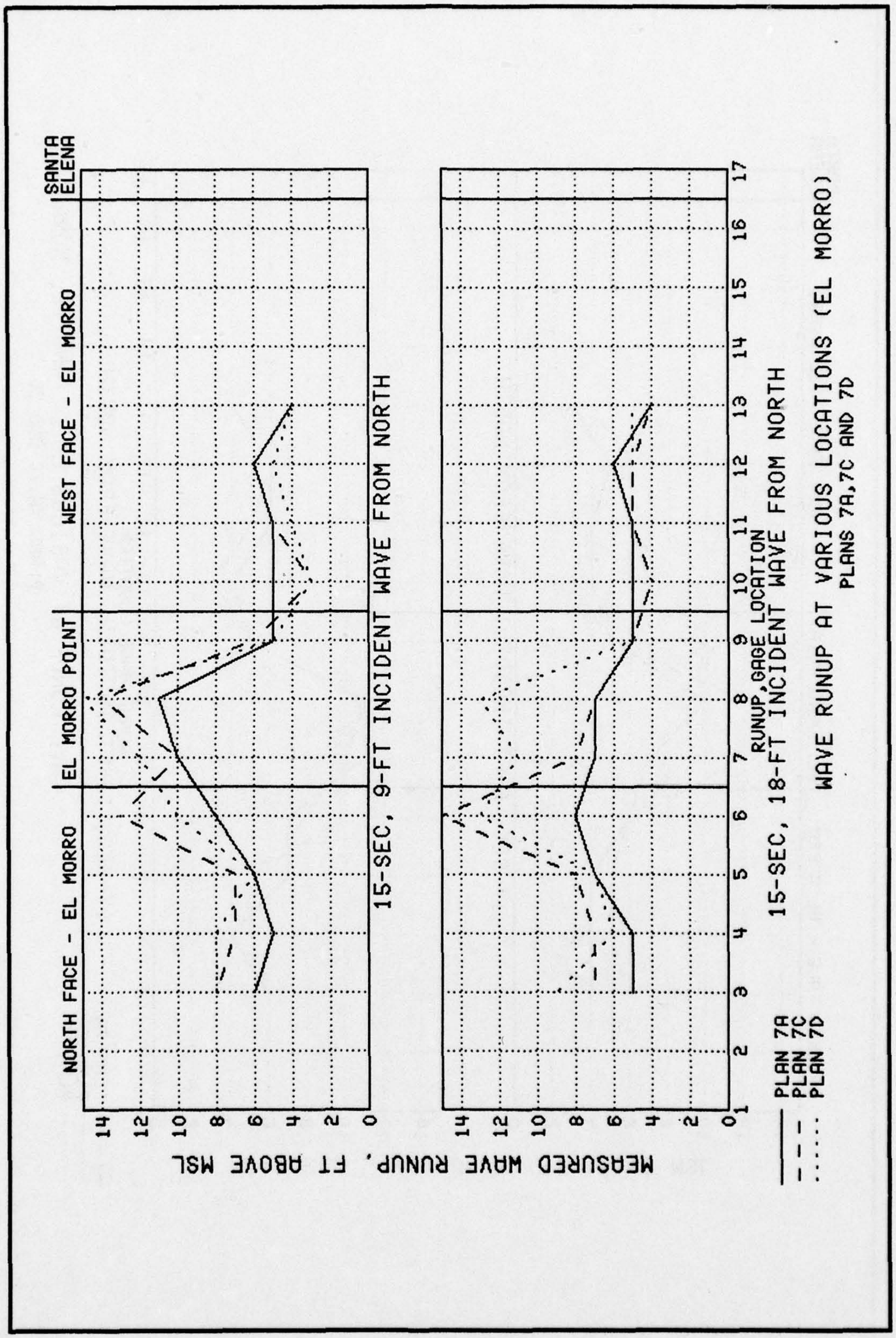
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
11-SEC, 8-FT INCIDENT WAVE FROM NORTH
11-SEC, 16-FT INCIDENT WAVE FROM NORTH
RUNUP GAGE LOCATION
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

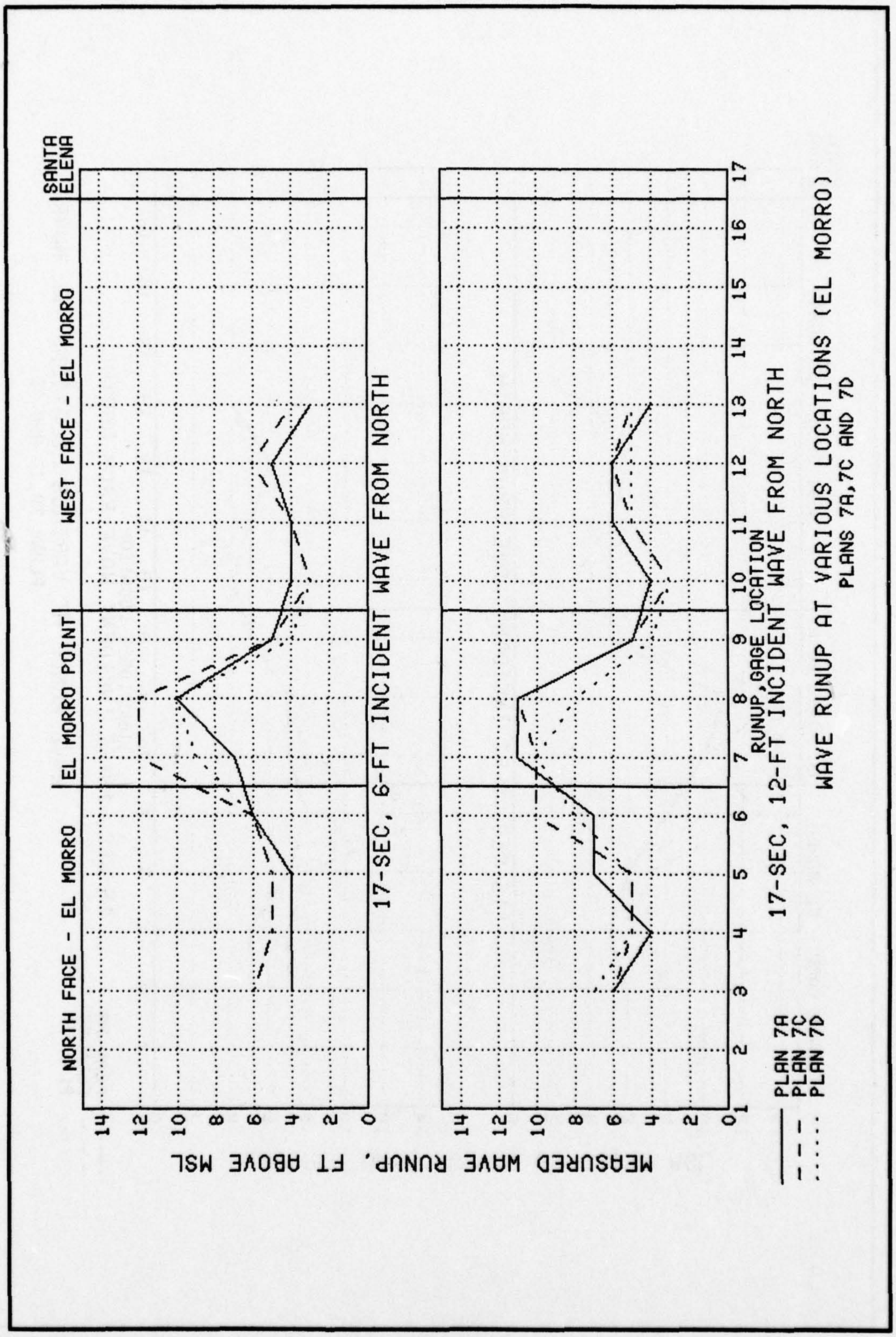


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

PLATE 158

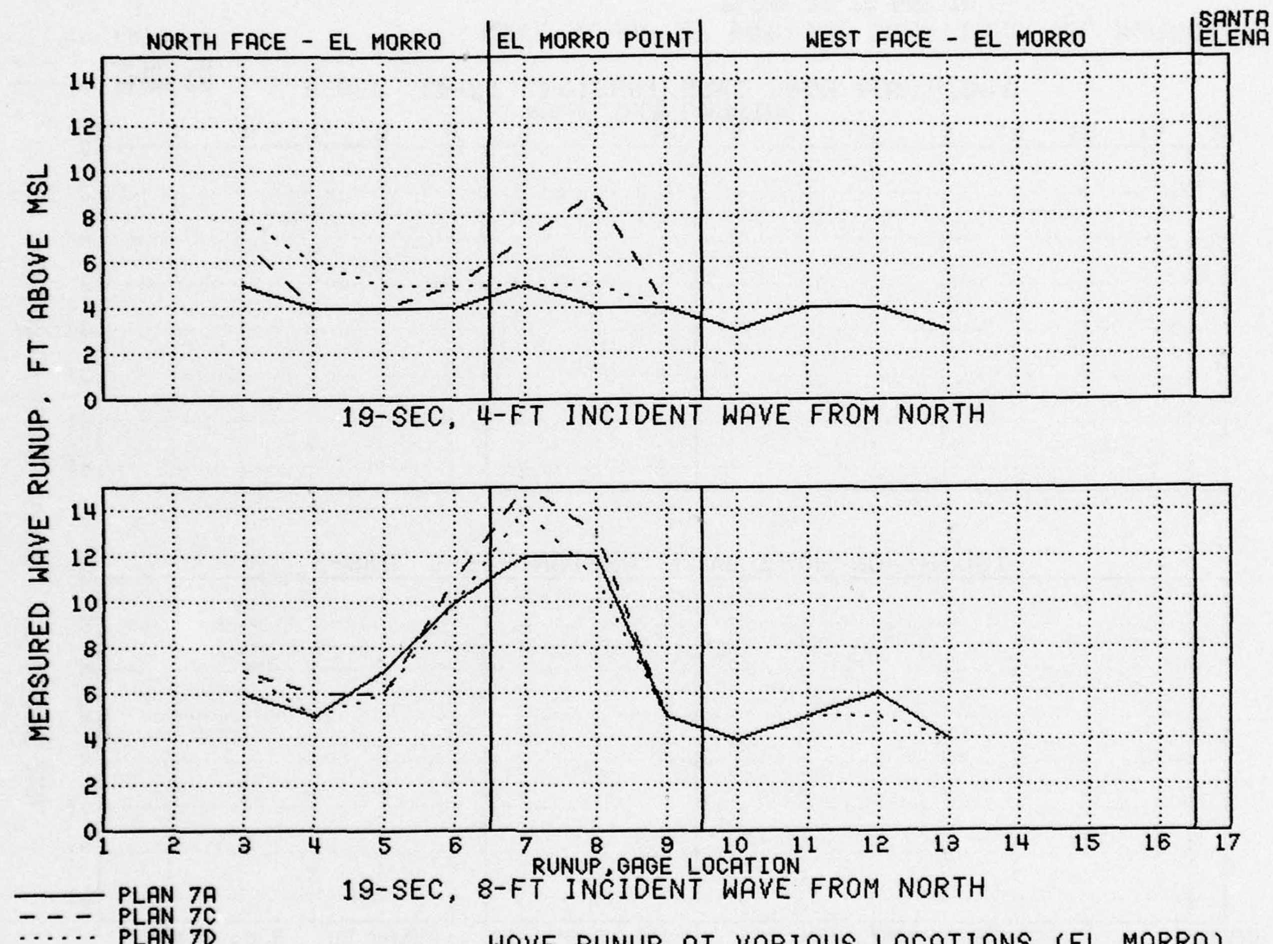


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D

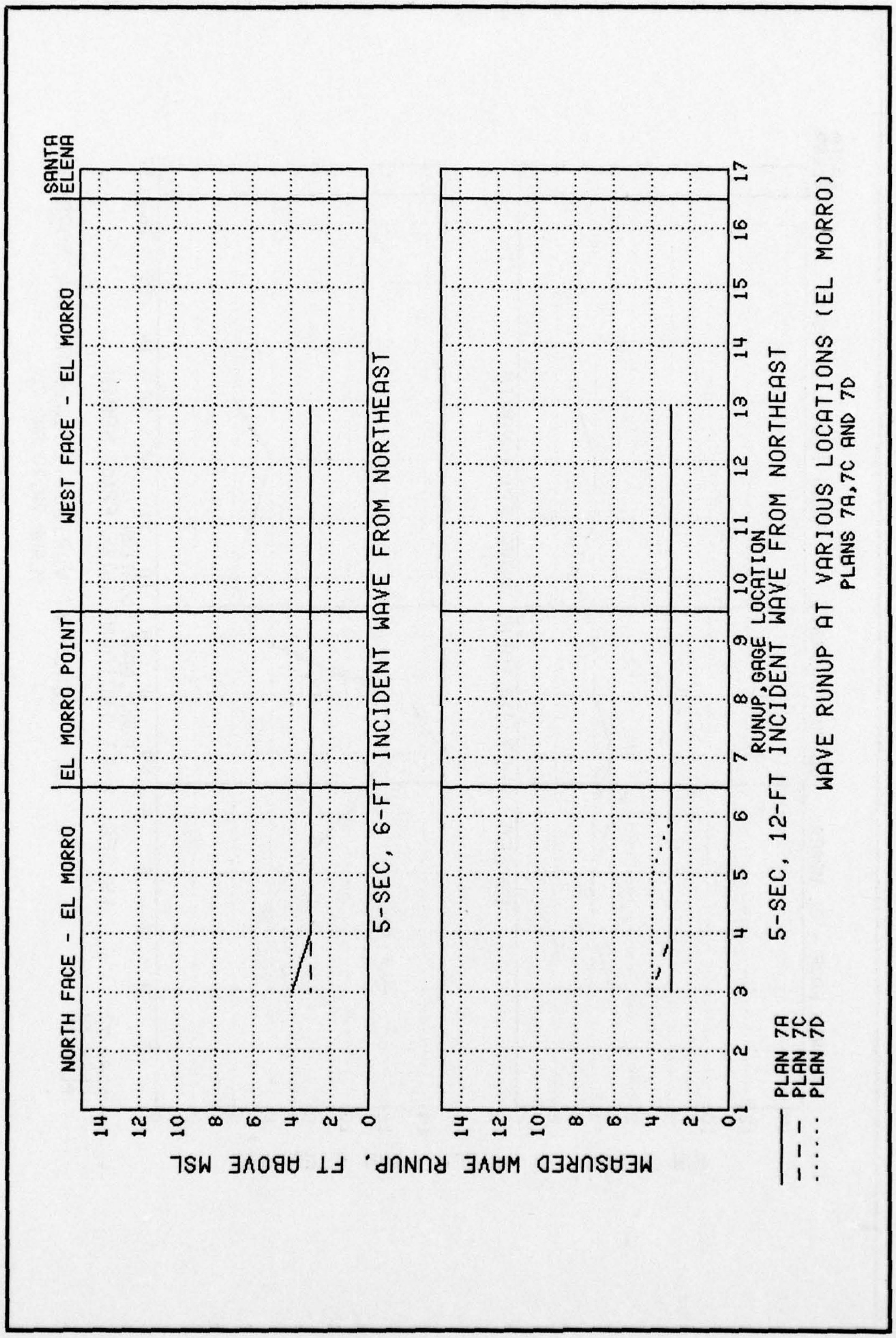


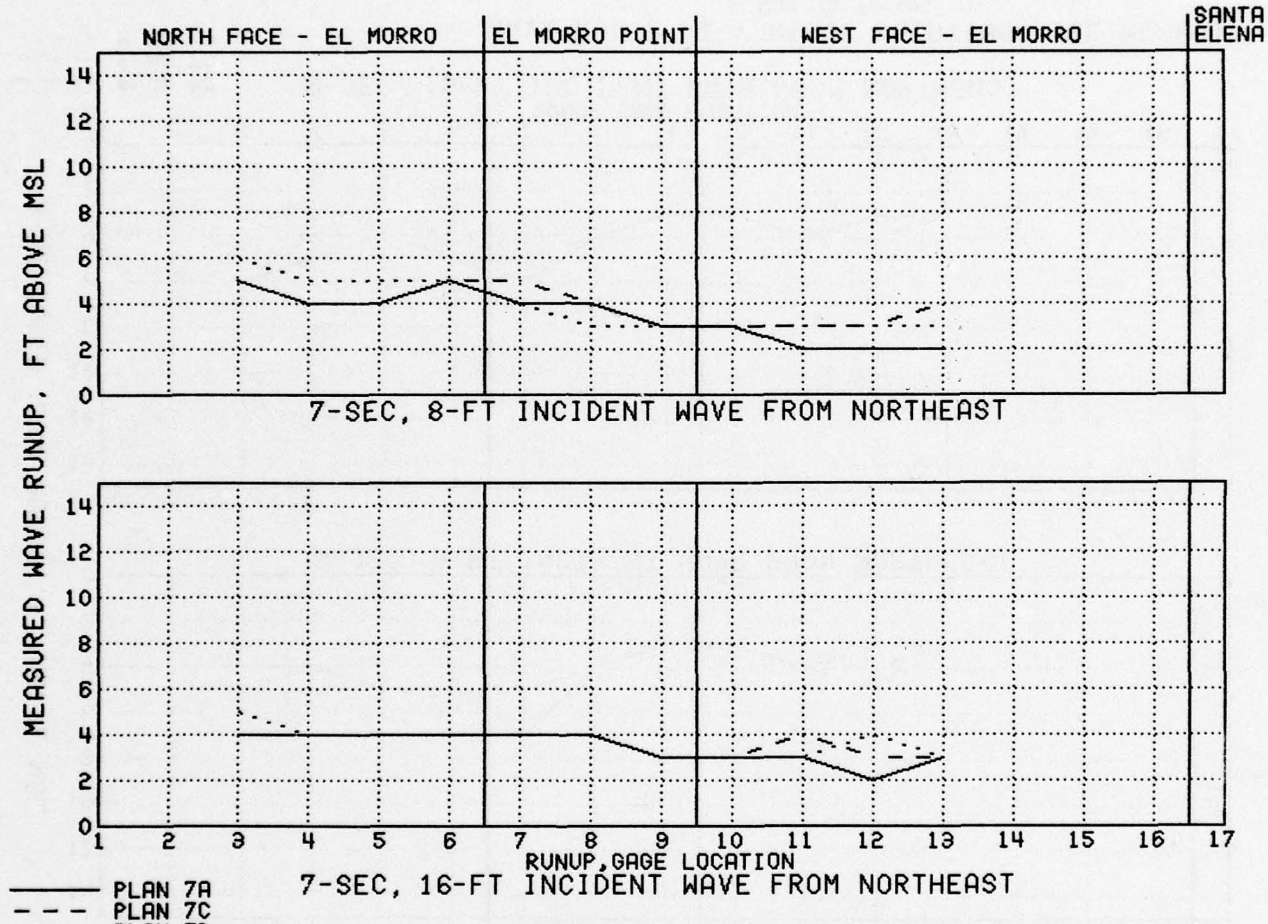
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
17-SEC, 6-FT INCIDENT WAVE FROM NORTH
17-SEC, 12-FT INCIDENT WAVE FROM NORTH
RUNUP GAGE LOCATION
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

PLATE 160

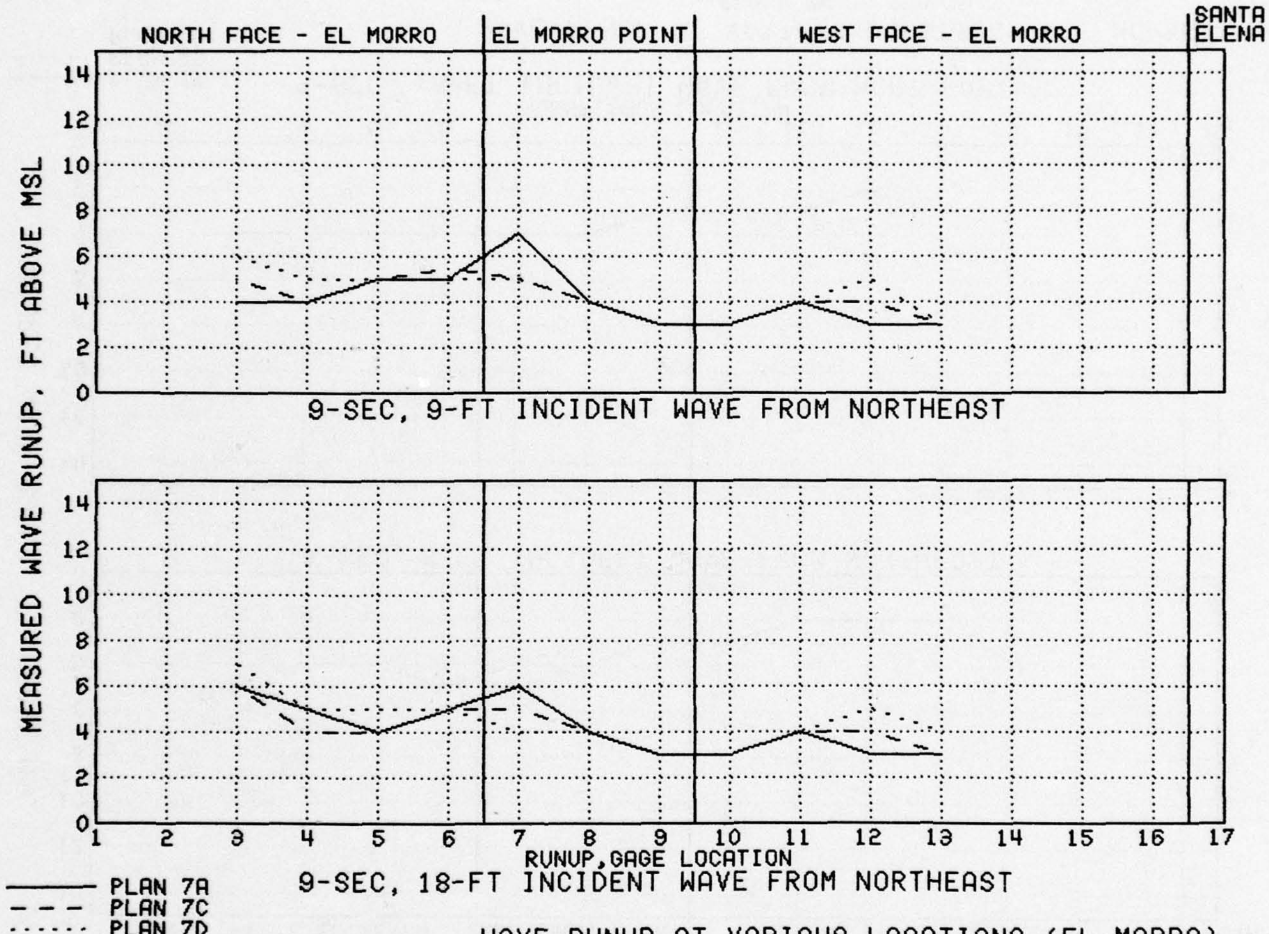


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D
5-SEC, 6-FT INCIDENT WAVE FROM NORTHEAST
5-SEC, 12-FT INCIDENT WAVE FROM NORTHEAST
MEASURED WAVE RUNUP, FT ABOVE MSL
RUNUP, GAGE LOCATION
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
PLAN 7A
PLAN 7C
PLAN 7D
0
2
4
6
8
10
12
14
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

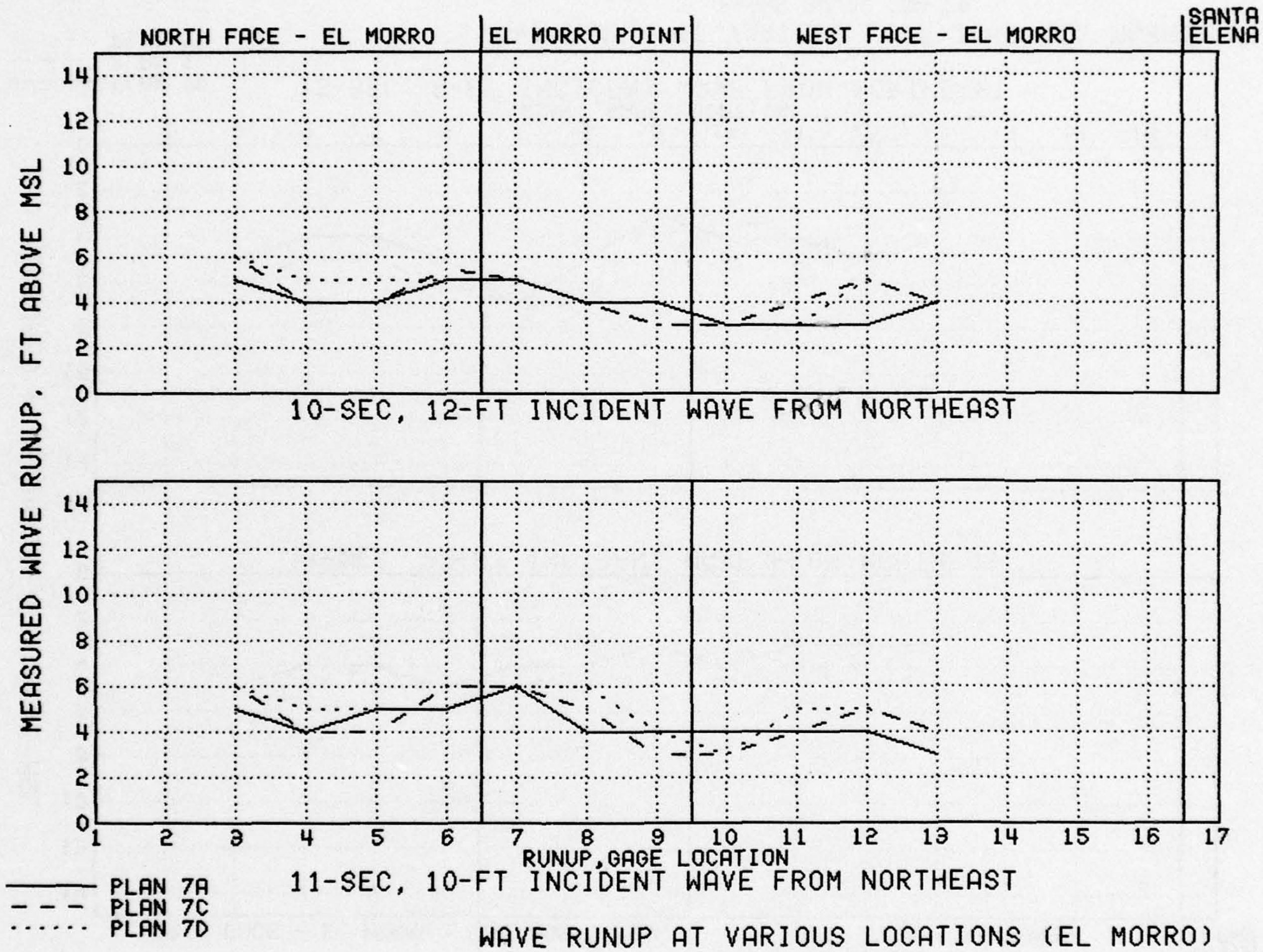


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

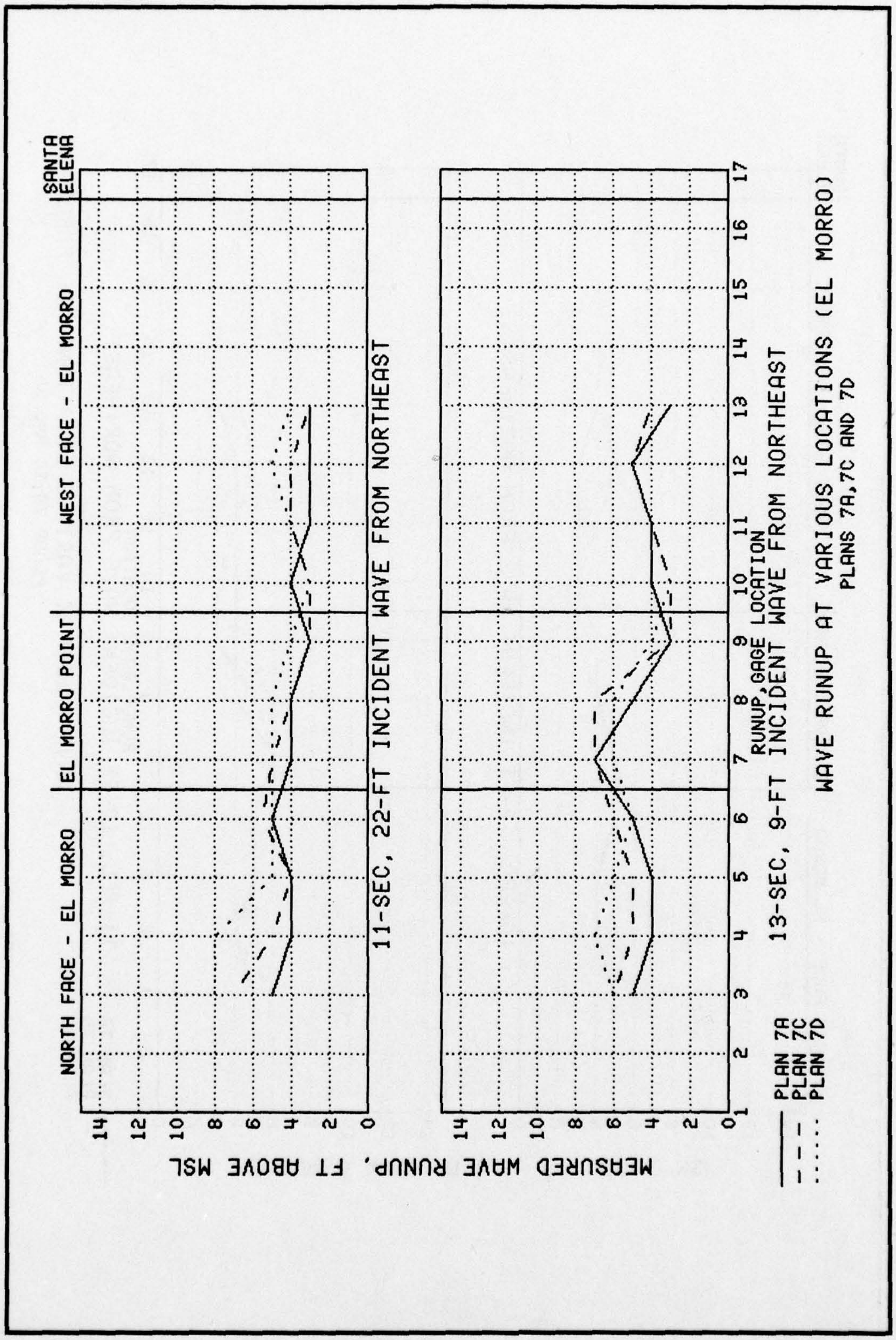


WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

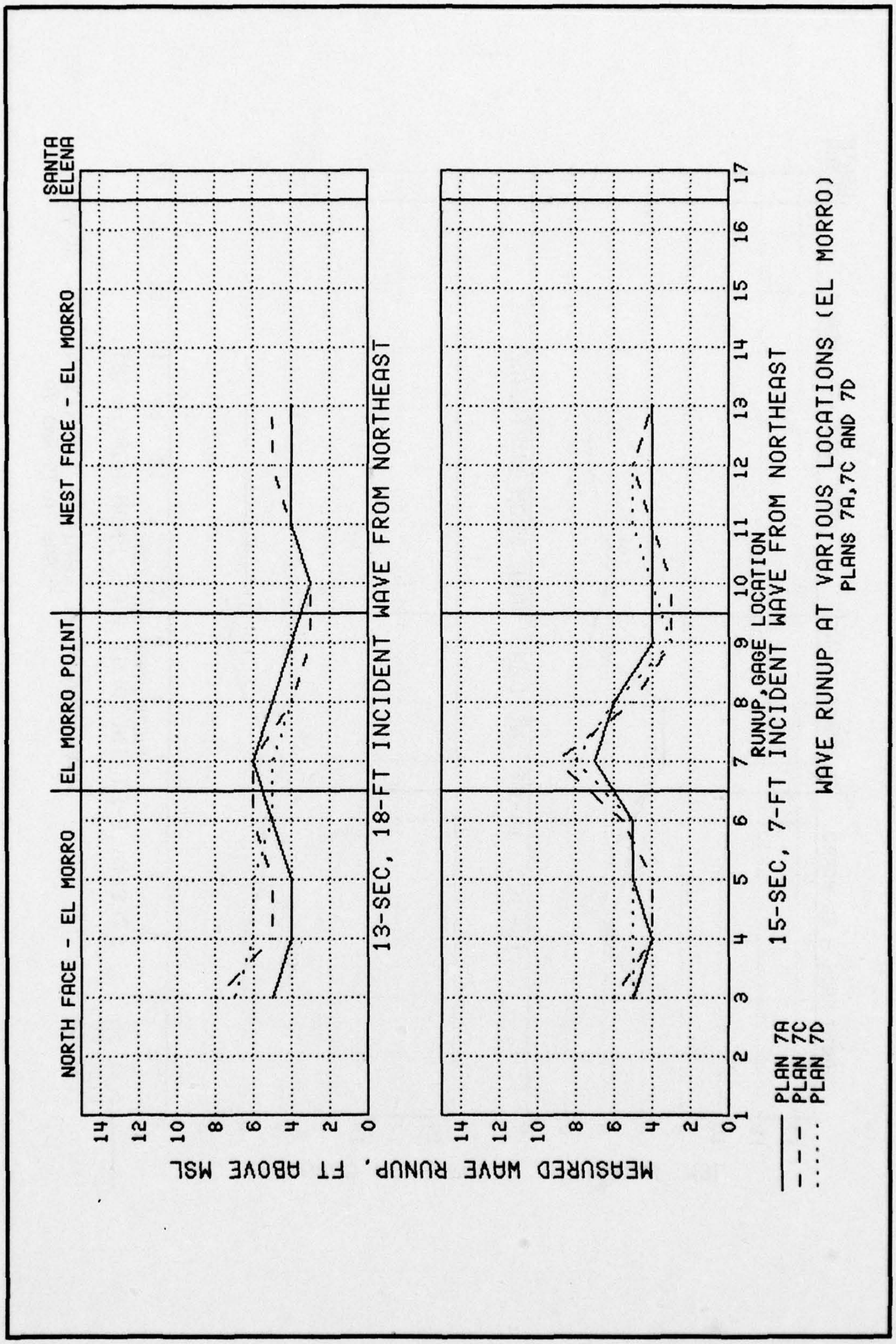
PLATE 164



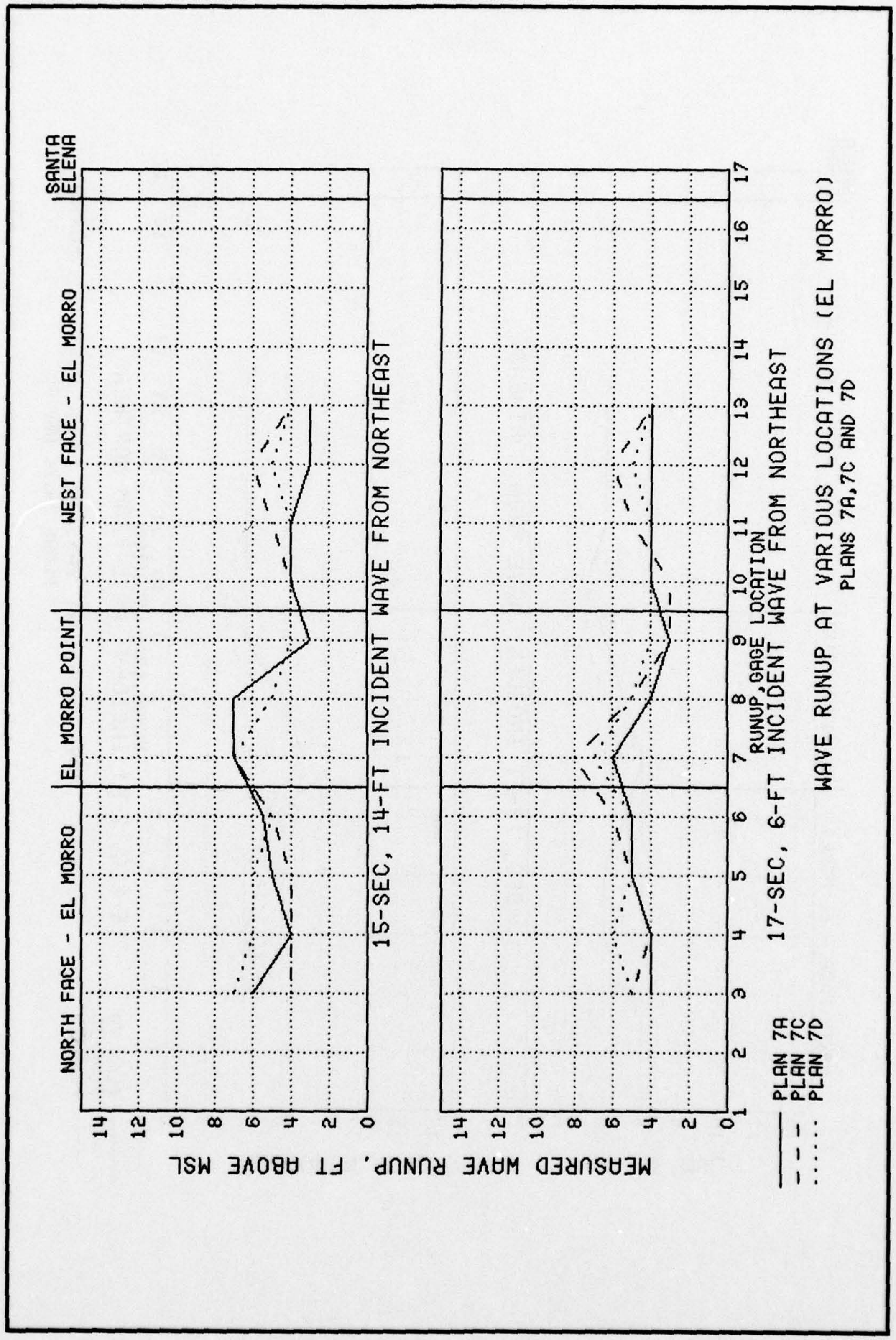
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D



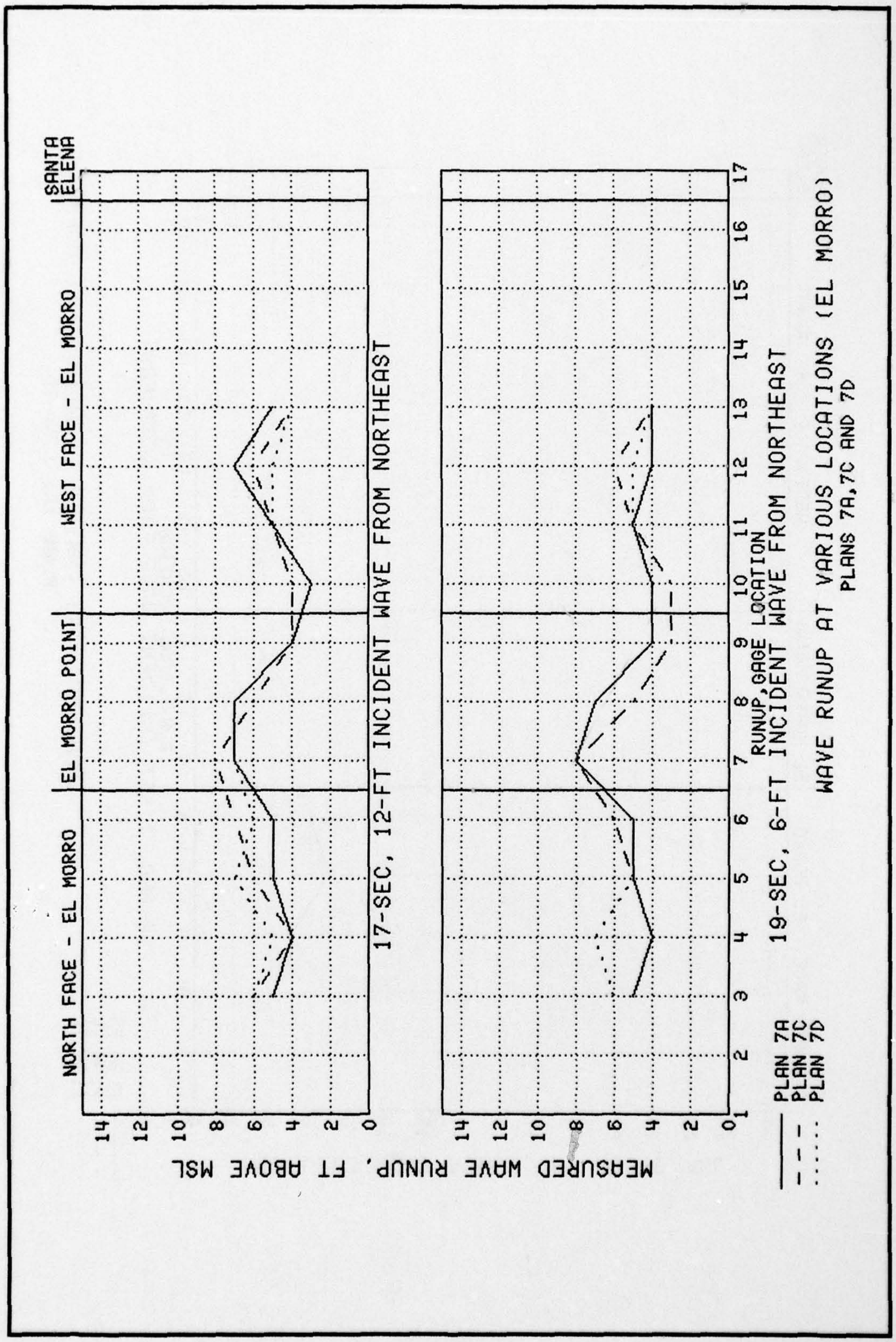
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



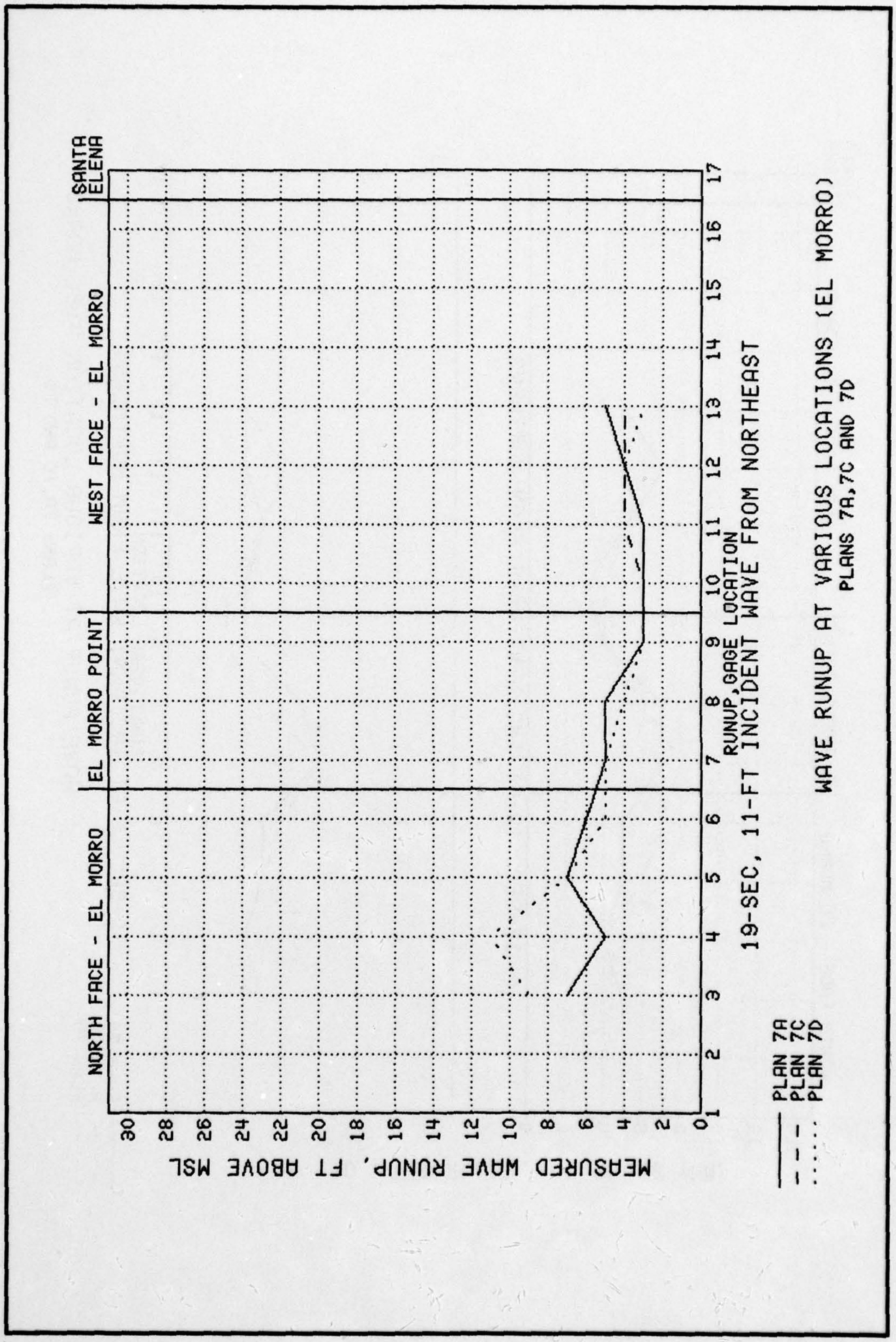
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
13-SEC, 18-FT INCIDENT WAVE FROM NORTHEAST
15-SEC, 7-FT INCIDENT WAVE FROM NORTHEAST
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



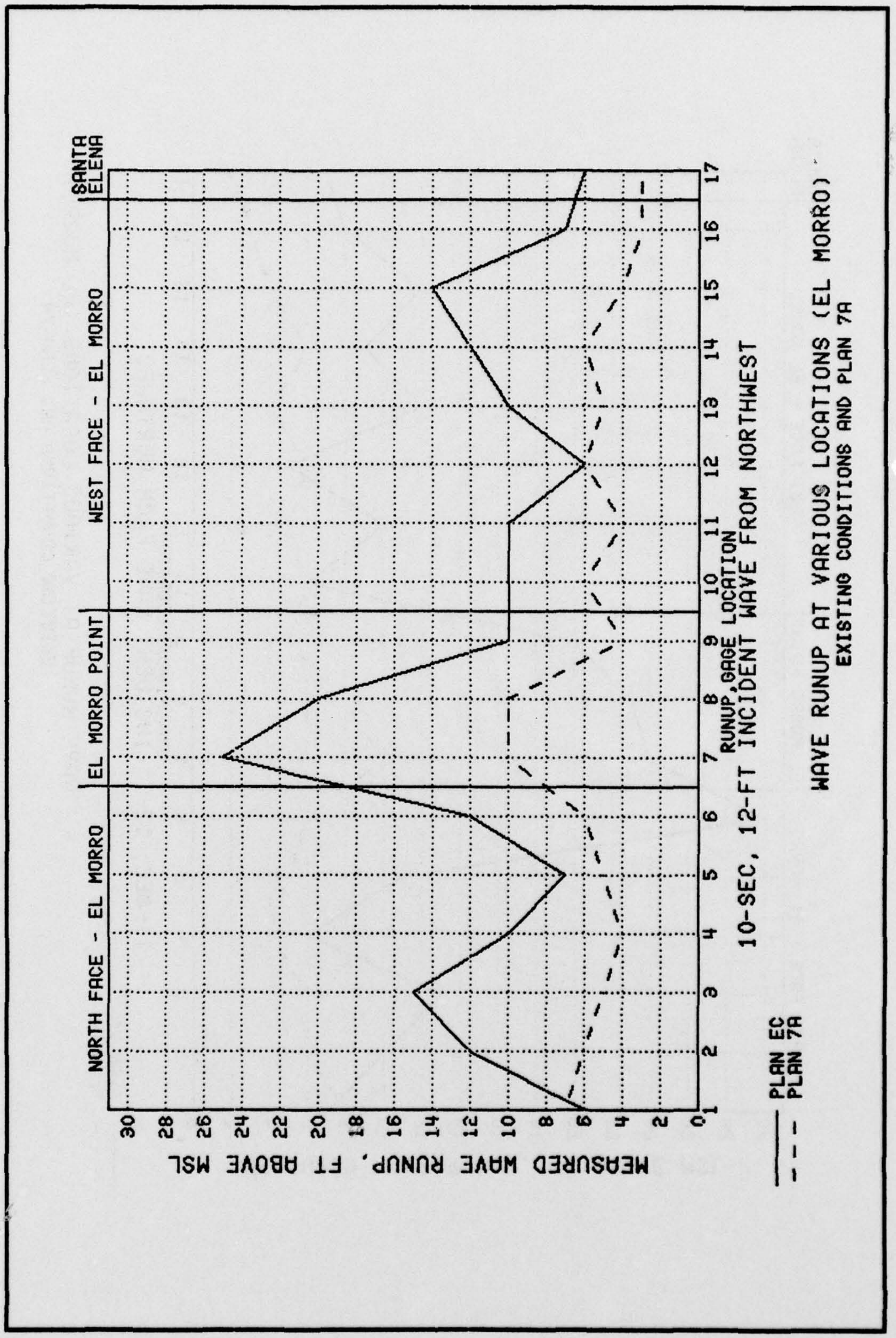
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
15-SEC, 14-FT INCIDENT WAVE FROM NORTHEAST
17-SEC, 6-FT INCIDENT WAVE FROM NORTHEAST
RUNUP GAGE LOCATION
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A, 7C AND 7D

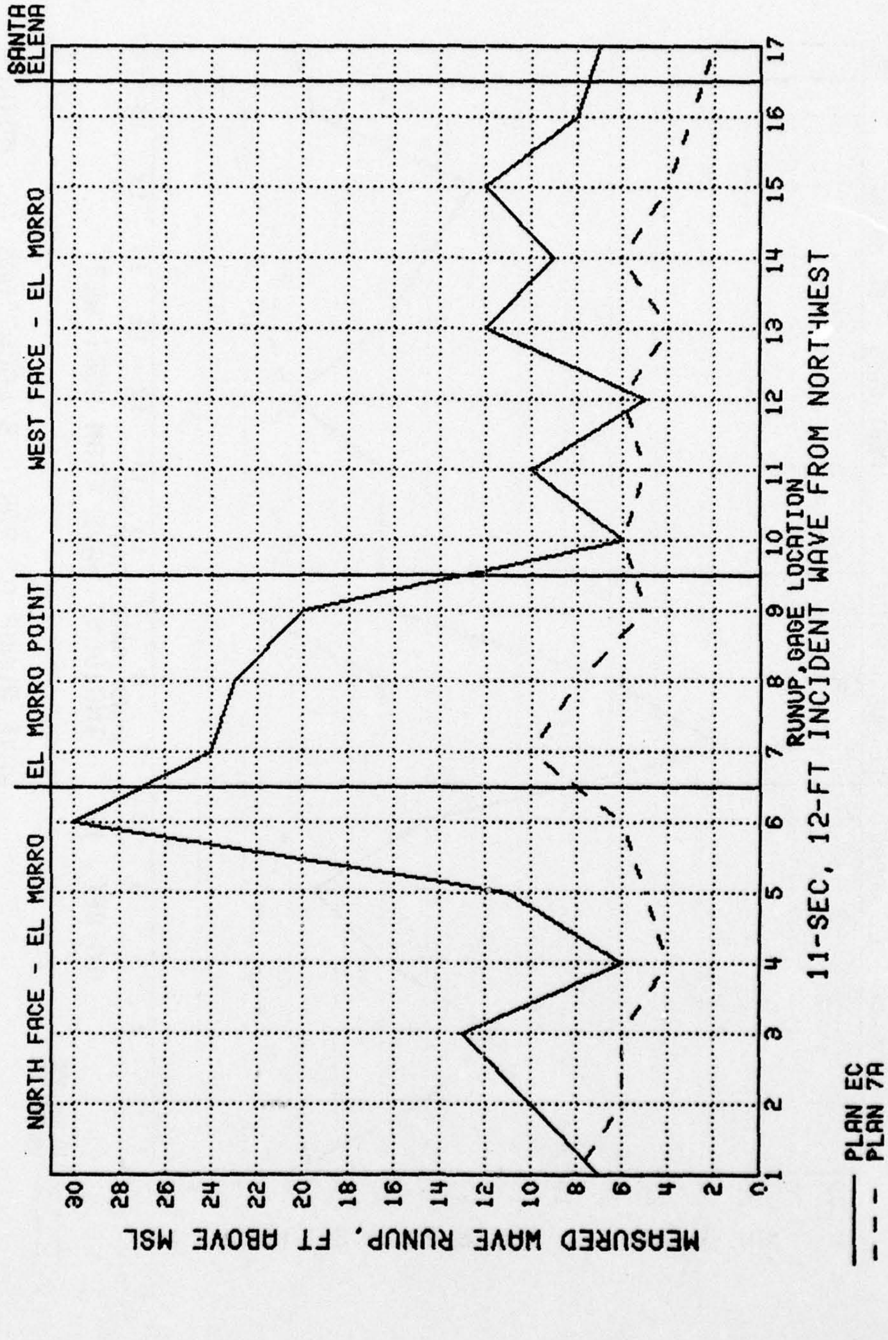


NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP,GAGE LOCATION
19-SEC, 11-FT INCIDENT WAVE FROM NORTHEAST
PLAN 7A
PLAN 7C
PLAN 7D
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
PLANS 7A,7C AND 7D

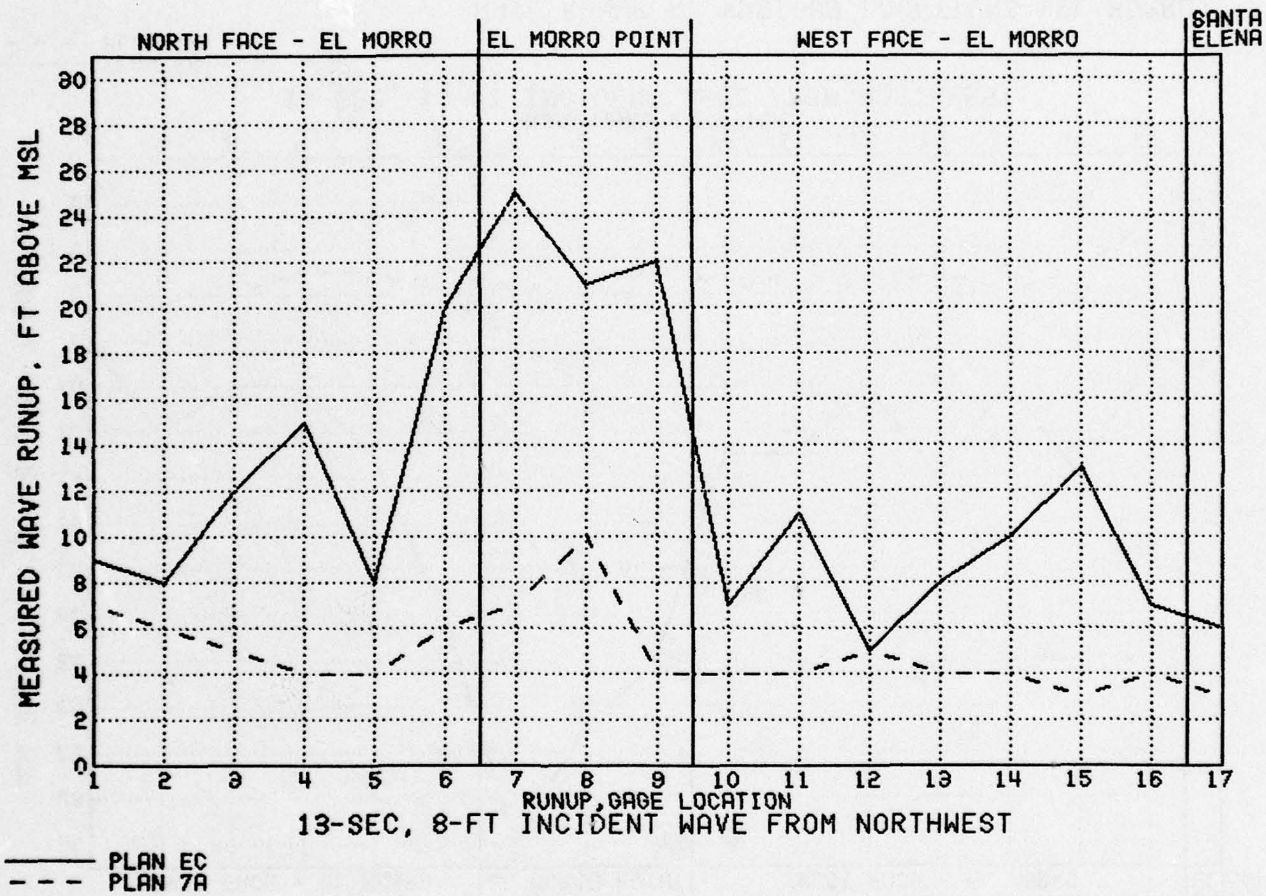


10-SEC, 12-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A

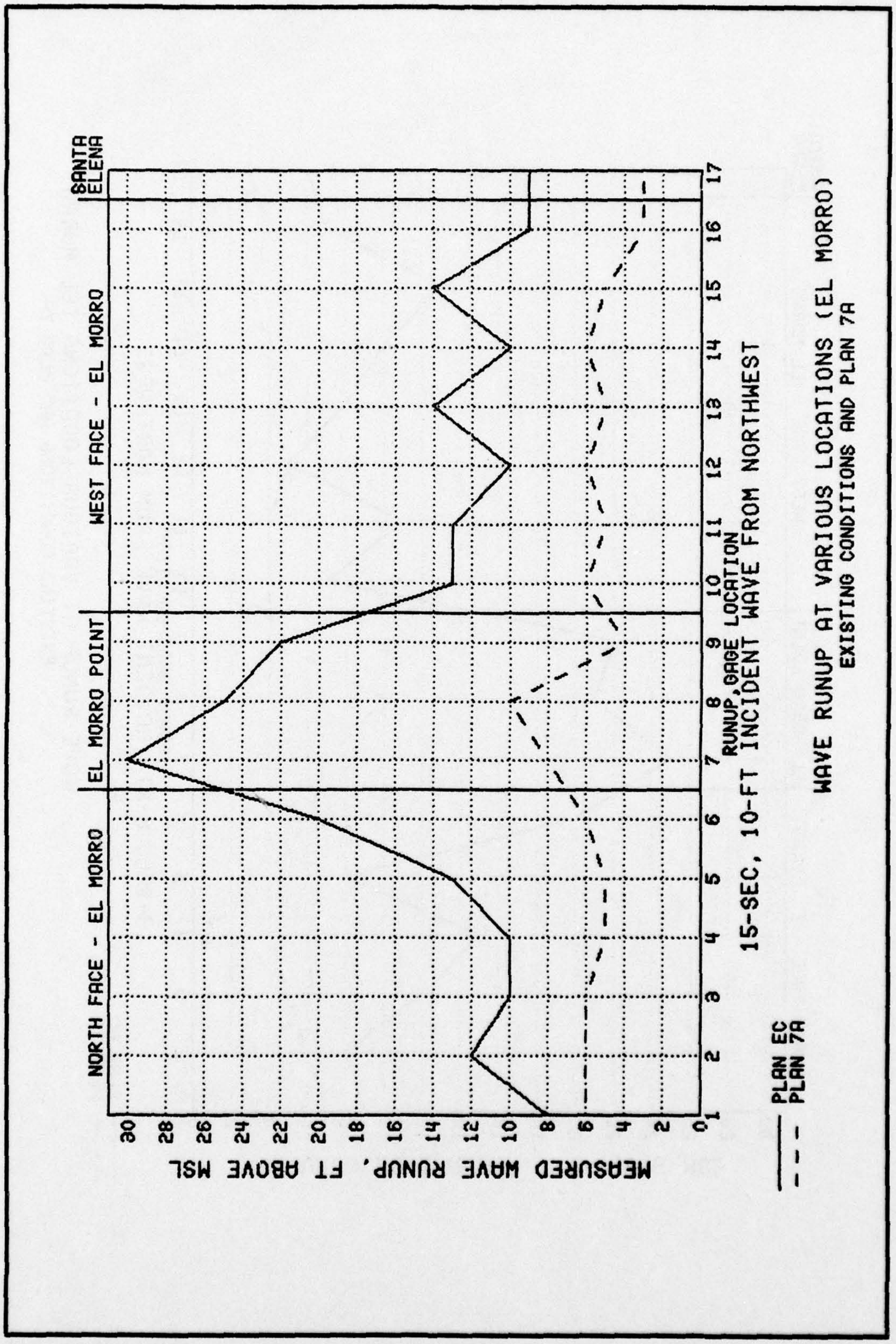


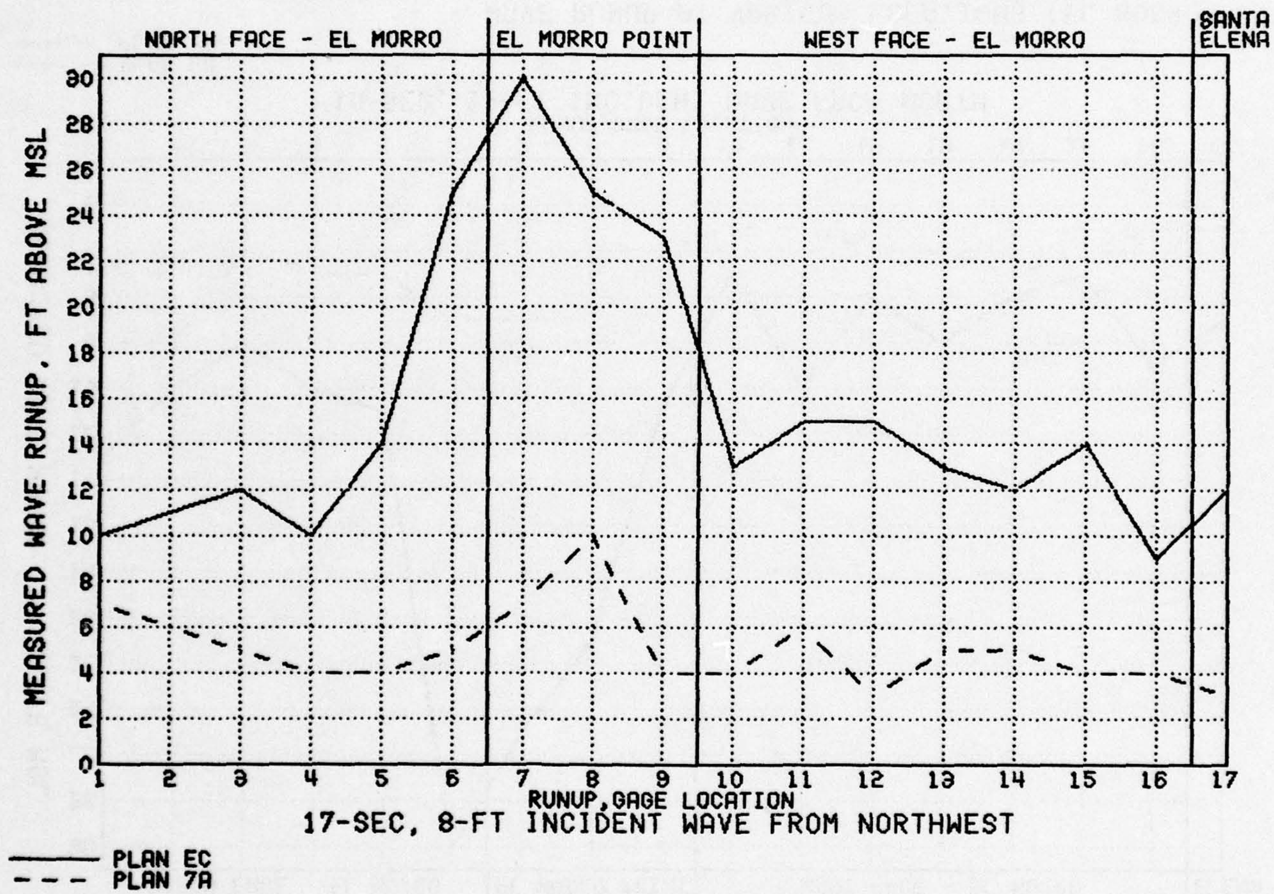
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



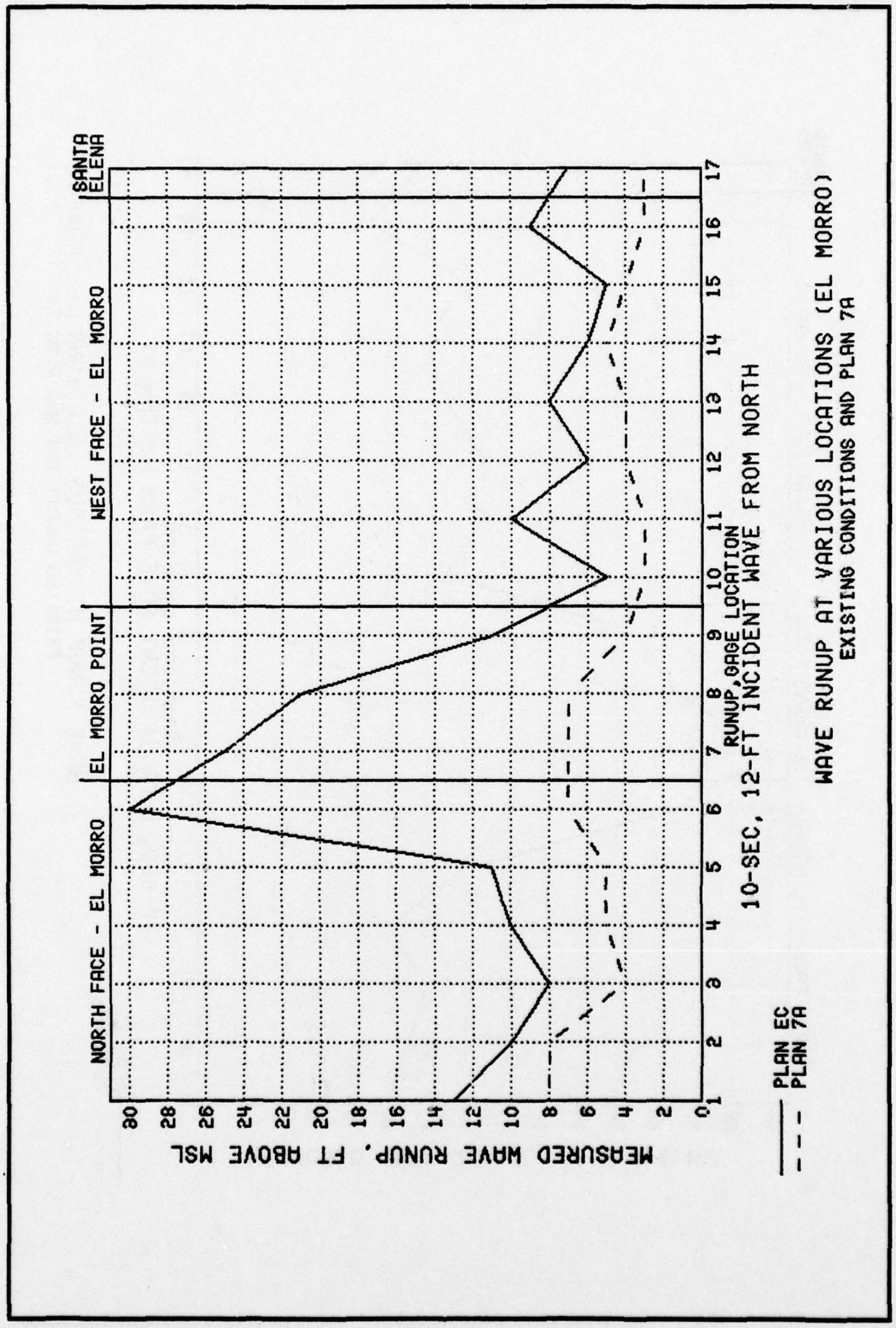
13-SEC, 8-FT INCIDENT WAVE FROM NORTHWEST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A

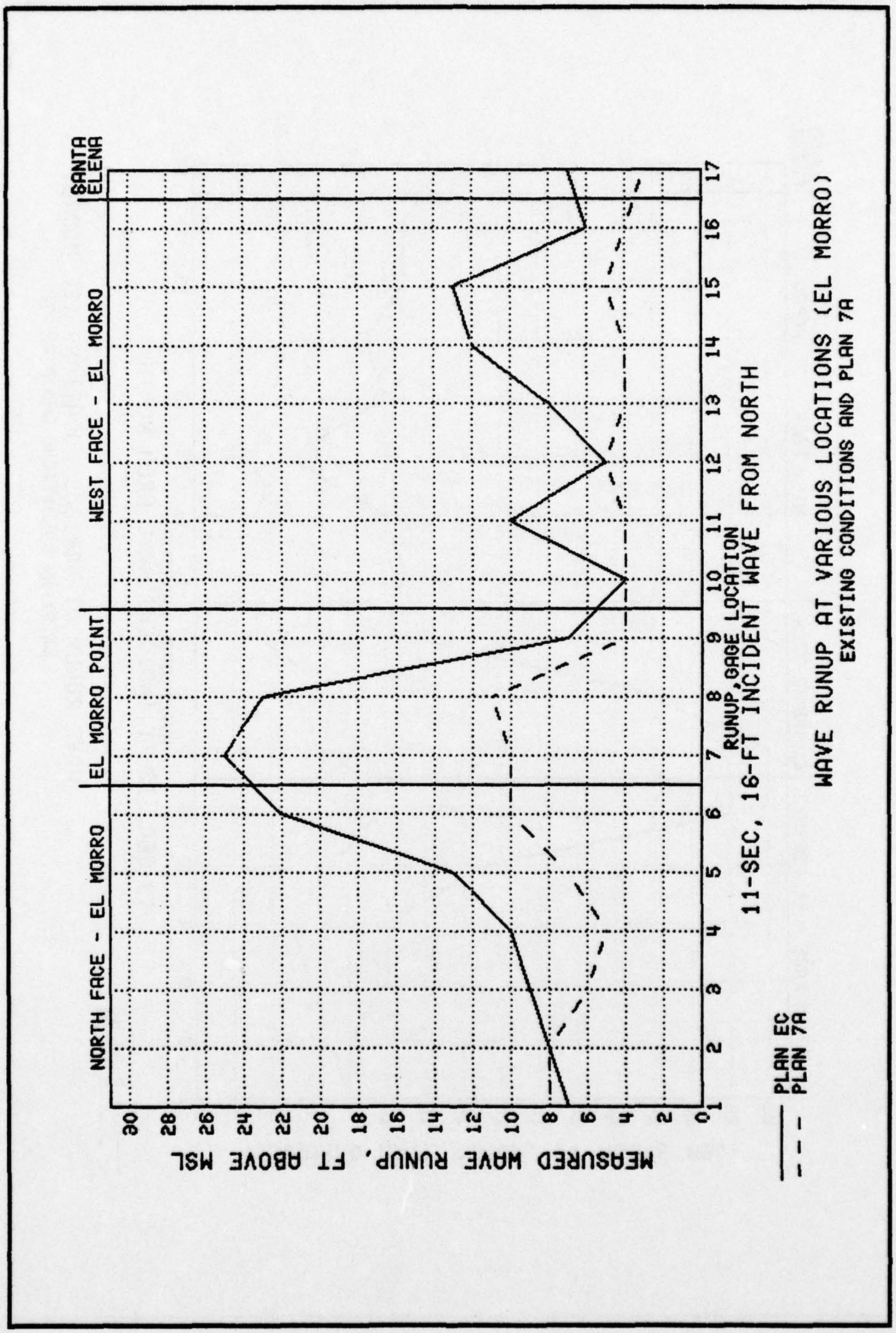

MEASURED WAVE RUNUP, FT ABOVE MSL
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
RUNUP GAGE LOCATION
15-SEC, 10-FT INCIDENT WAVE FROM NORTHWEST
PLAN EC
PLAN 7A
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



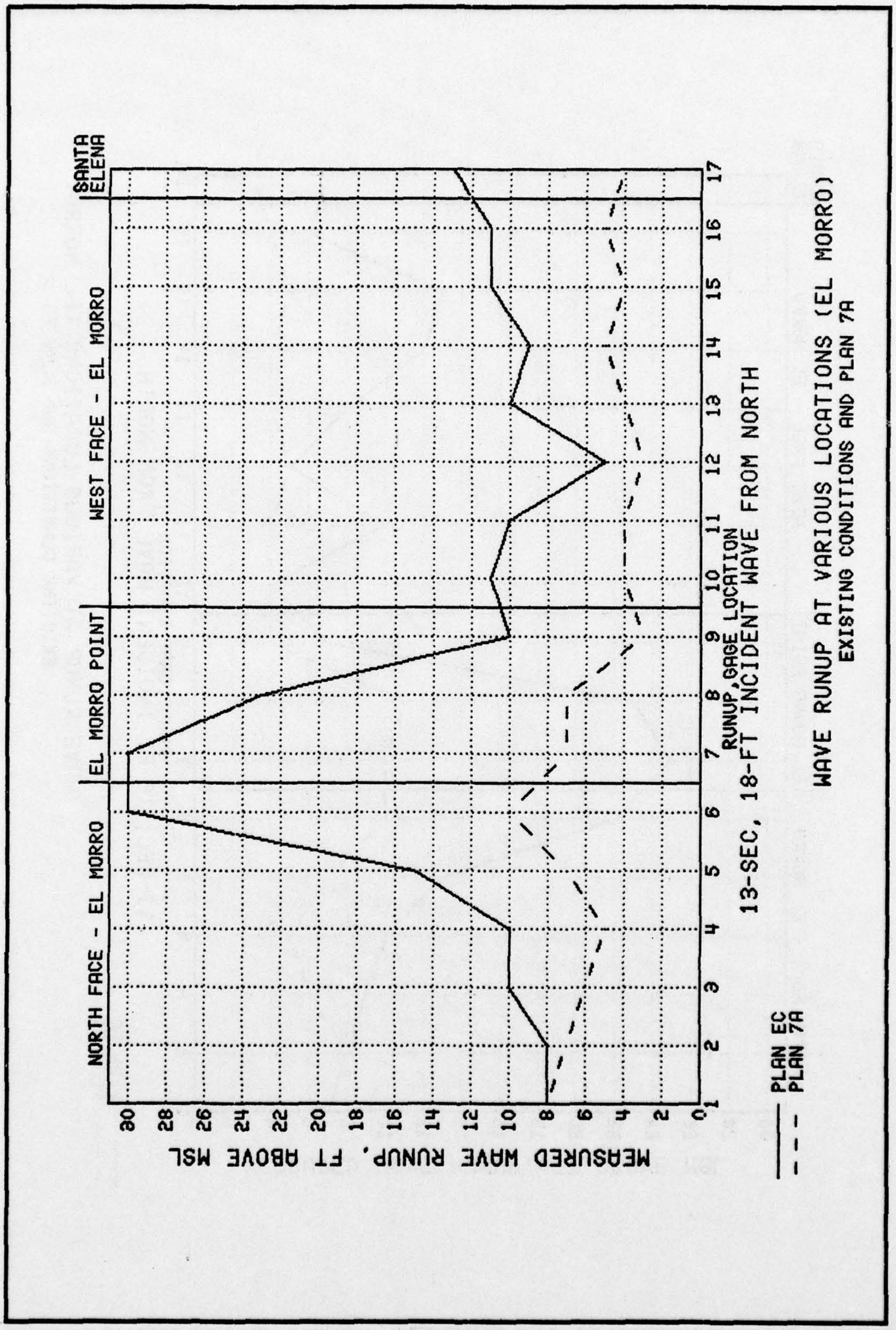
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



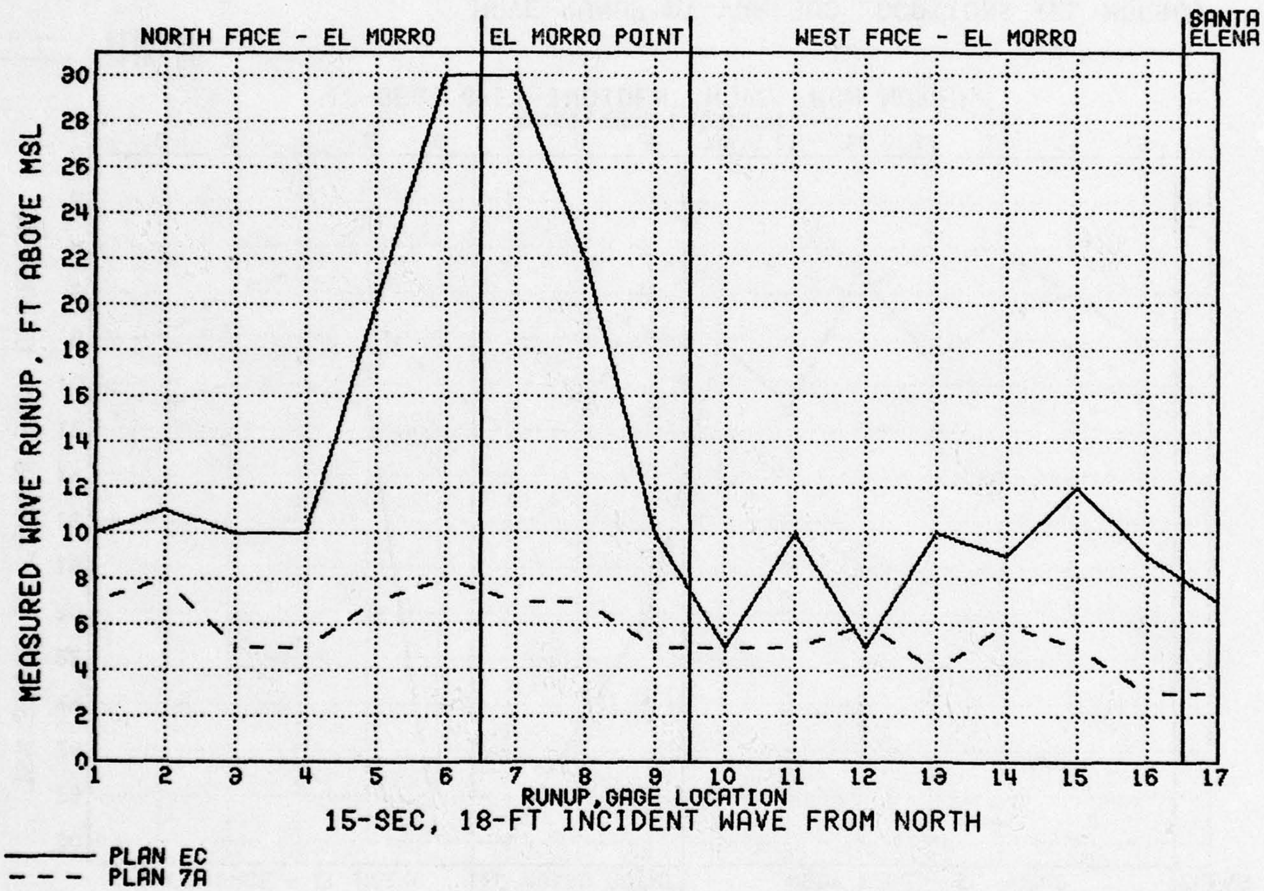
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



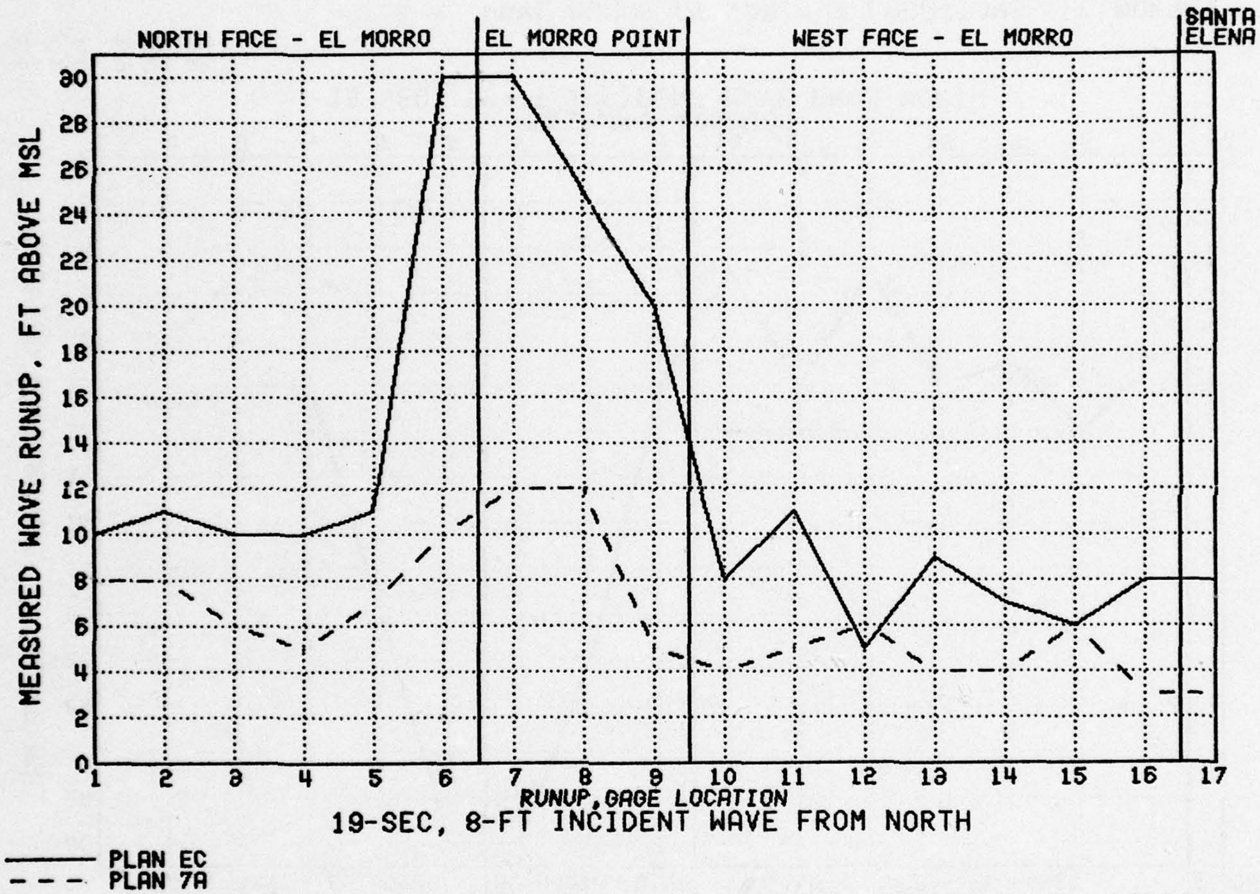
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
11-SEC, 16-FT INCIDENT WAVE FROM NORTH
PLAN EC
PLAN 7A
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



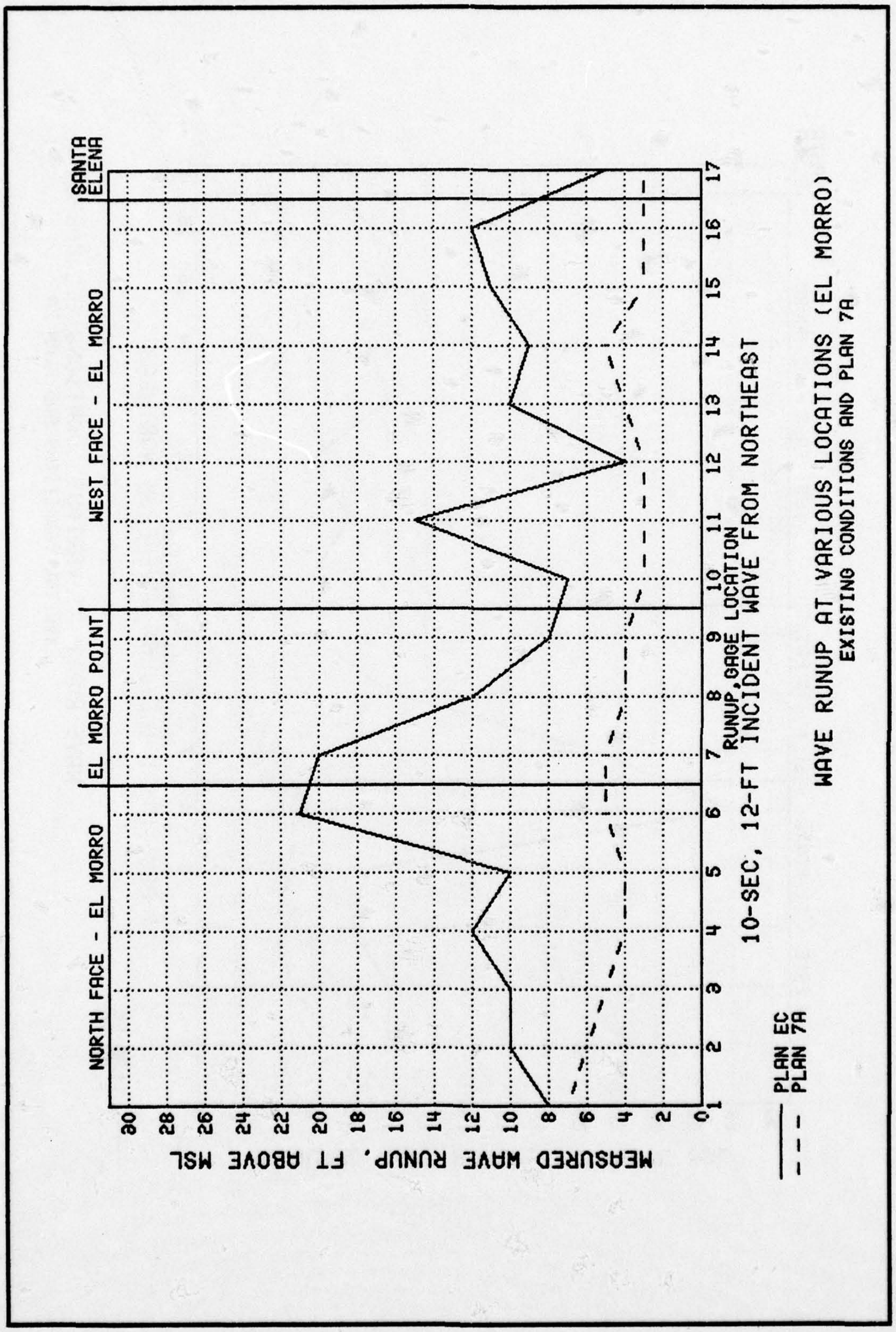
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
RUNUP GAGE LOCATION
13-SEC, 18-FT INCIDENT WAVE FROM NORTH
PLAN EC
PLAN 7A
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



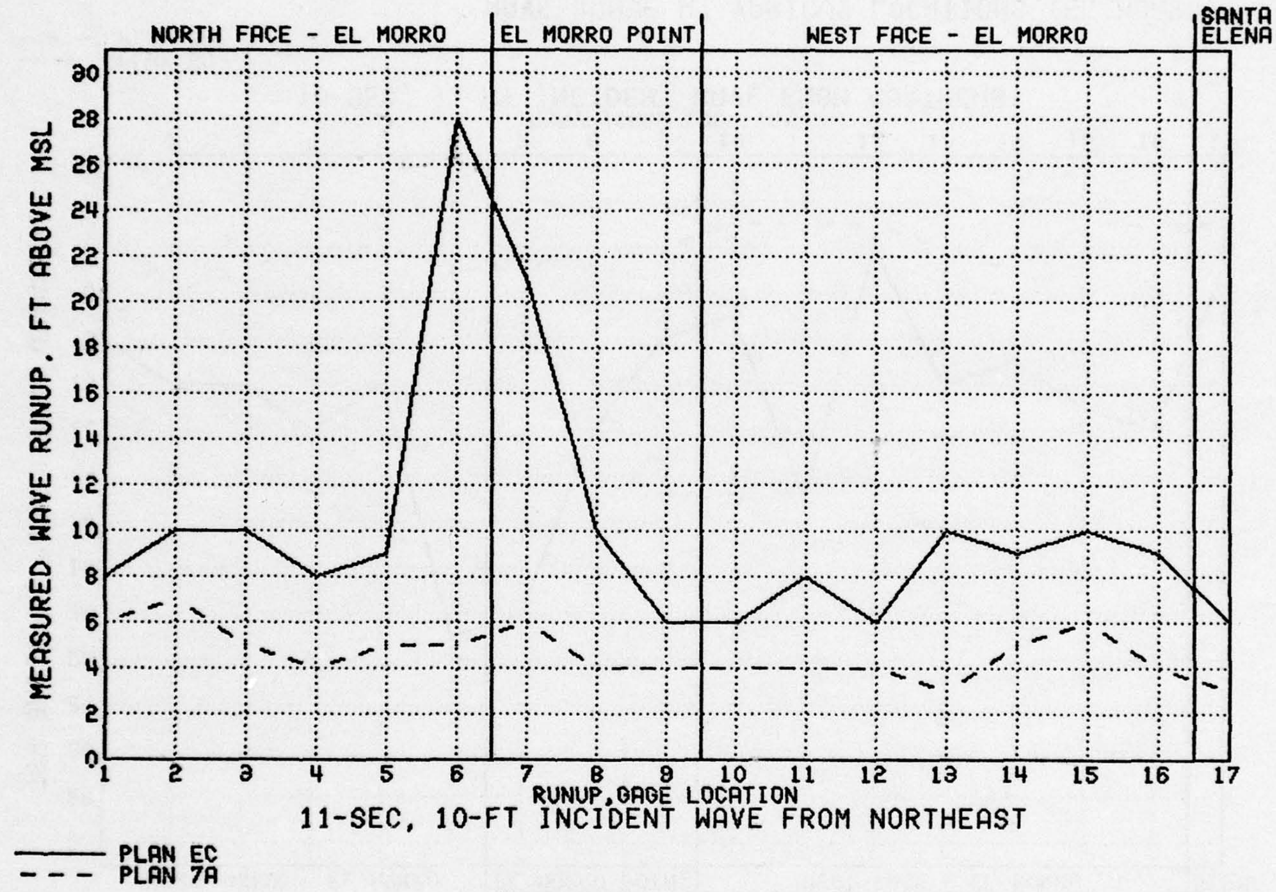
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



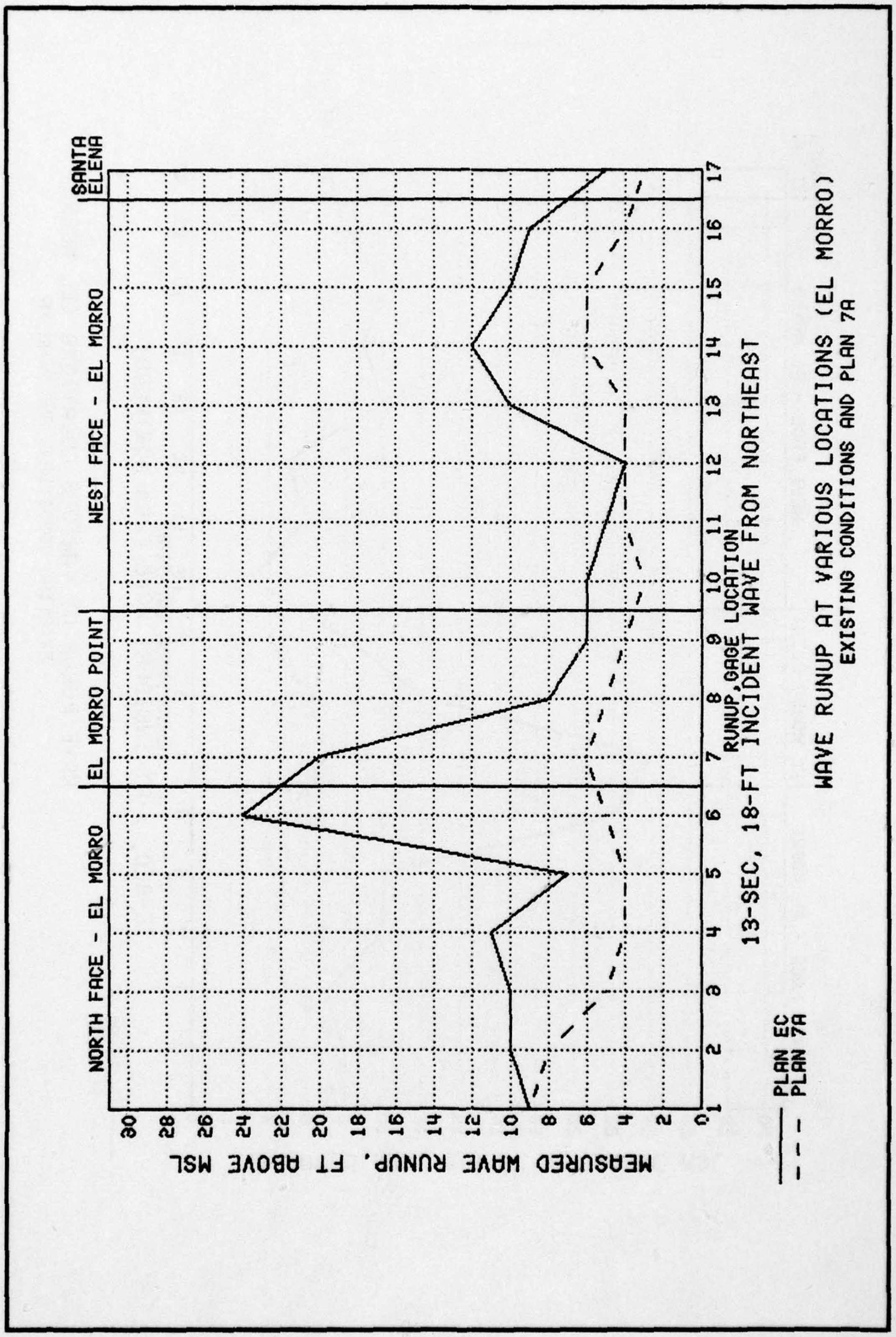
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



11-SEC, 10-FT INCIDENT WAVE FROM NORTHEAST

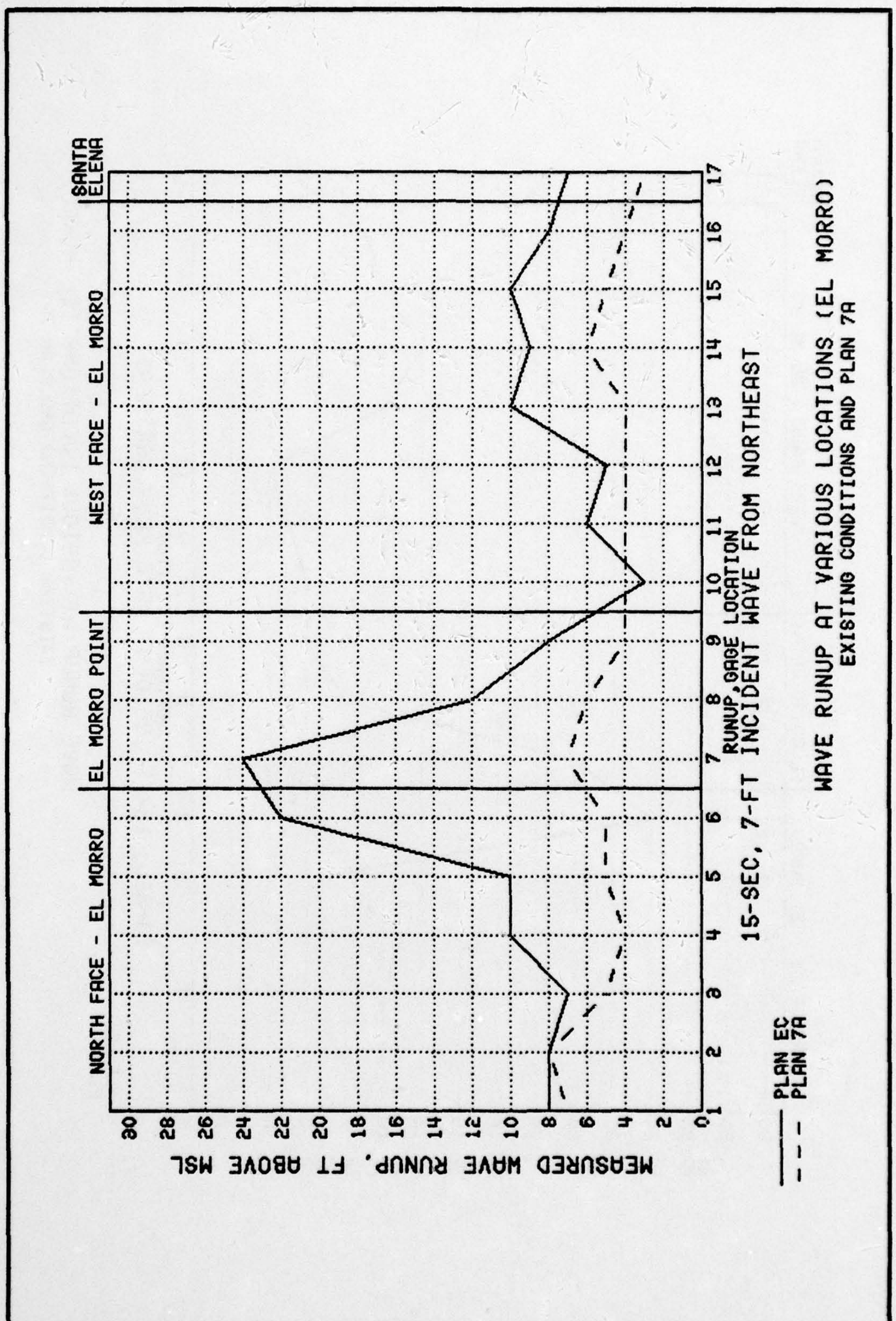
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A

PLATE 182

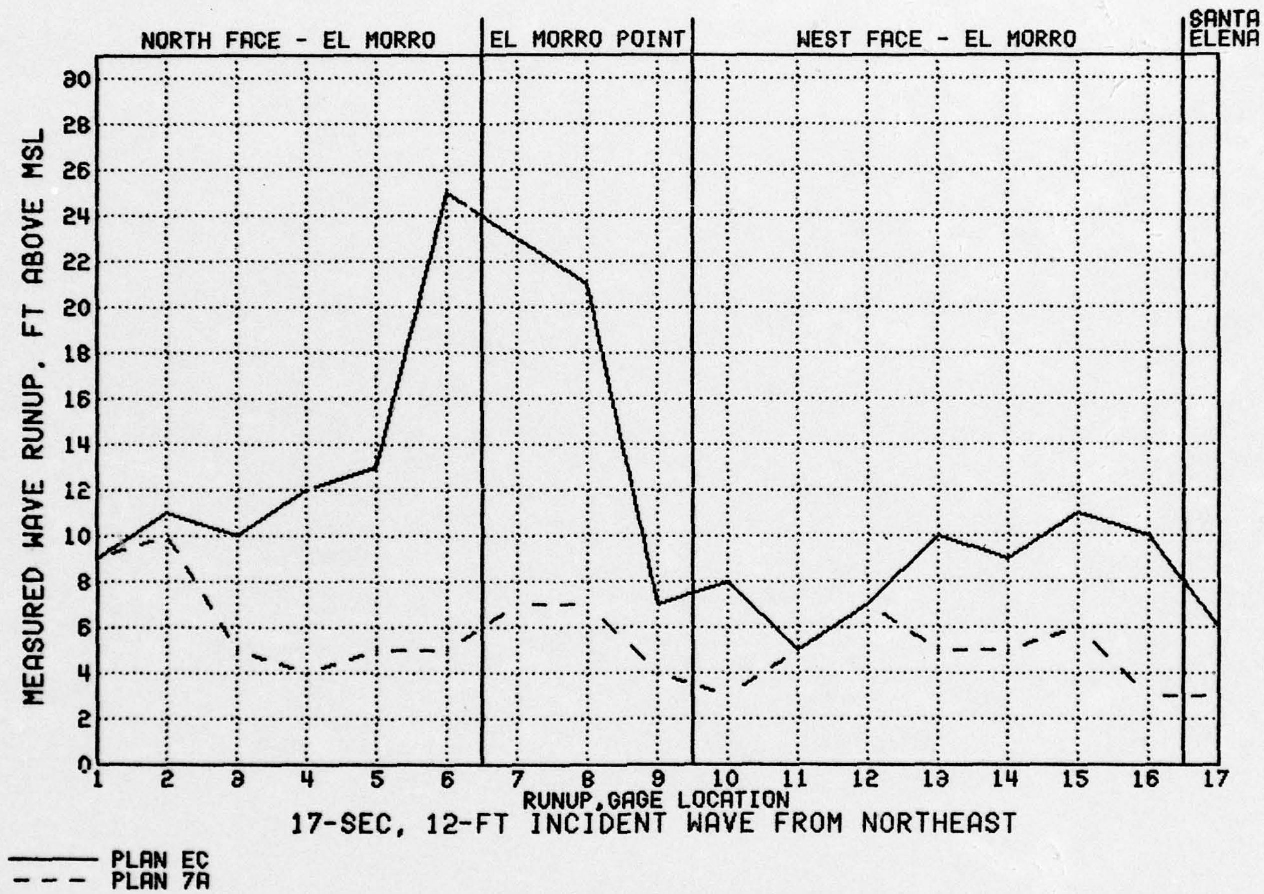


13-SEC, 18-FT INCIDENT WAVE FROM NORTHEAST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



MEASURED WAVE RUNUP, FT ABOVE MSL
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
NORTH FACE - EL MORRO
EL MORRO POINT
WEST FACE - EL MORRO
SANTA ELENA
RUNUP GAGE LOCATION
15-SEC, 7-FT INCIDENT WAVE FROM NORTHEAST
PLAN EC
PLAN 7A
WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A



17-SEC, 12-FT INCIDENT WAVE FROM NORTHEAST

WAVE RUNUP AT VARIOUS LOCATIONS (EL MORRO)
EXISTING CONDITIONS AND PLAN 7A

APPENDIX A: WAVE-REFRACTION ANALYSIS FOR SAN JUAN NATIONAL HISTORIC SITE

1. Prior to the hydraulic model investigation of San Juan National Historic Site, a wave-refraction analysis was conducted at the U. S. Army Engineer Waterways Experiment Station (WES) to determine the shallow-water wave height and the refracted wave direction at the model wave generator pit for representative wave periods from the critical directions of deepwater wave approach. This analysis was conducted using a linear wave-refraction theory originally developed at Stanford University by Dobson (1967)* and modified by WES in 1971. All computations and plotting were done using the Honeywell 635 computer and Calcomp drum plotter at WES.

2. In this analysis, the effects of both reflection and diffraction are neglected. These assumptions are valid except in convergence areas where caustics occur and linear theory does not apply. Therefore, the major assumption in determining the wave height at any point on a wave orthogonal, within the limits of the linear theory, is that no energy is transmitted perpendicular to the orthogonal along the wave crest, in which case the height at any point is given by

$$H = H_o K_s K_r$$

where

H_o = wave height in deep water

K_s = shoaling coefficient

K_r = refraction coefficient

This assumption has been shown to be reasonable for mild slopes which induce only gradual bending of the orthogonals. For areas of extreme refraction, failure to consider the flow of energy along the wave crests can lead to significant errors in the computed wave height. Since previous research at WES by Whalin (1971, 1972) has shown that wave

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* See References at the end of main text.

energy will tend to flow along the wave crests in areas of energy concentration, a maximum refraction coefficient of 1.4 and a minimum refraction coefficient of 0.45 were selected as being reasonable values.

3. Refraction diagrams for the San Juan National Historic Site were produced from a rectangular depth grid (4.5 miles by 2.2 miles) which paralleled the shoreline in the vicinity of the project site and extended seaward to where depths were approximately equal to one half the deepwater wavelength for wave periods from the various directions. Limits of the depth grid used are shown in Plate A1. The grid spacing was 300 ft and depths were taken from the latest hydrographic survey charts.

4. Wave orthogonals were produced for 6-, 8-, 10-, 12-, 14-, 16-, and 18-sec waves from the northwest, north, and northeast. The plots obtained are shown in Plates A2-A22.

5. Refraction coefficients and shallow-water orthogonal directions obtained for the various wave periods from the three deepwater wave directions are presented in Table A1. These values represent an average of the orthogonals in the immediate vicinity of the historic site (approximately the location of the wave generator in the model). Shoaling coefficients of 0.96, 0.91, 0.92, 0.95, 0.99, 1.04, and 1.09 for 6-, 8-, 10-, 12-, 14-, 16-, and 18-sec wave periods, respectively, were computed for a 60-ft water depth corresponding to the simulated depth at the model wave generator. The wave-height adjustment factor is obtained by multiplying K_r times K_s and can be applied to any deepwater wave height to obtain the corresponding shallow-water value.

6. Based on refracted directions obtained at the -60 ft contour for each wave period, three wave generator positions were selected representing the various deepwater directions. The following tabulation shows the deepwater directions and the selected shallow-water test directions.

Deepwater Direction, deg	Selected Shallow-Water Test Direction, deg
NW, 315	334
North, 0	3
NE, 45	33

Table A1

Summary of Refraction and Shoaling Analysis

for San Juan National Historic Site

Deepwater Direction deg	Wave Period sec	Shallow-Water* Azimuth, deg	Refraction Coefficient	Shoaling Coefficient	Wave-Height Adjustment Factor
NW, 315	6	317.39	0.98	0.96	0.94
	8	324.70	0.92	0.91	0.84
	10	331.89	0.91	0.92	0.84
	12	337.22	0.92	0.95	0.87
	14	340.58	0.94	0.99	0.93
	16	343.35	0.99	1.04	1.03
	18	345.38	0.99	1.09	1.08
North, 0	6	0.37	1.00	0.96	0.96
	8	1.56	1.00	0.91	0.91
	10	2.93	1.00	0.92	0.92
	12	3.55	1.03	0.95	0.98
	14	4.91	1.08	0.99	1.07
	16	4.93	1.10	1.04	1.14
	18	5.32	1.11	1.09	1.21
NE, 45	6	43.86	1.00	0.96	0.96
	8	39.80	0.98	0.91	0.89
	10	35.62	0.98	0.92	0.90
	12	31.92	1.01	0.95	0.96
	14	29.51	1.01	0.99	1.00
	16	27.31	0.97	1.04	1.01
	18	25.46	1.03	1.09	1.12

* At 60-ft depth.

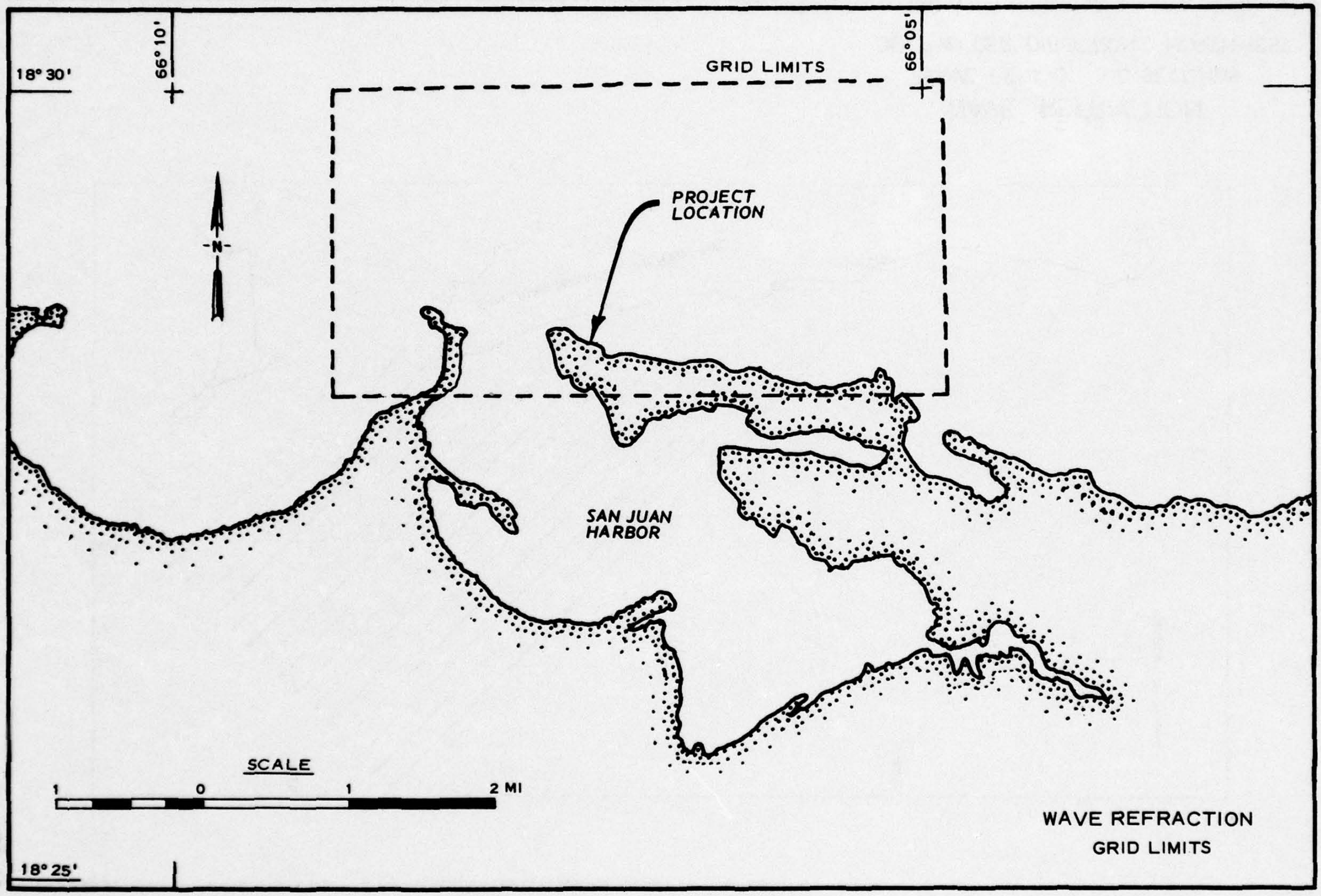
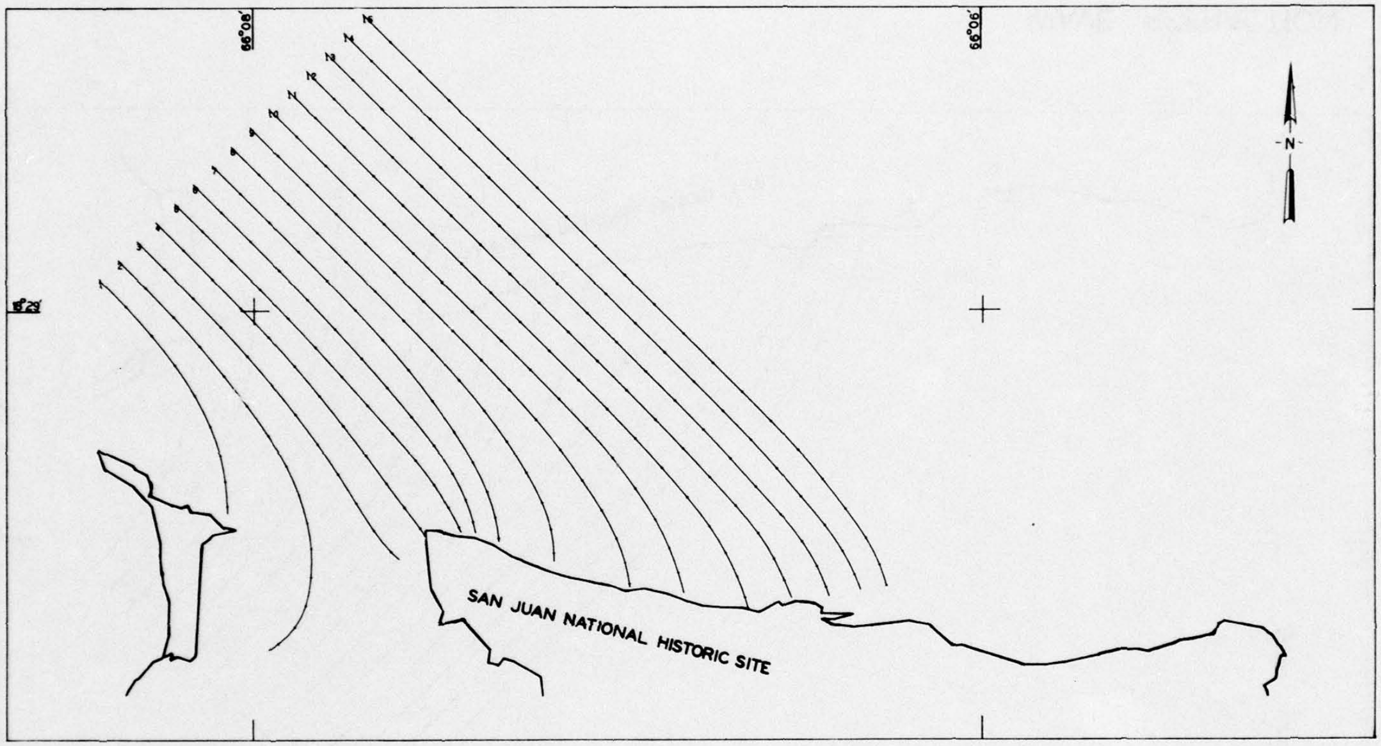

18° 30'
66° 10'
66° 05'
GRID LIMITS
N
PROJECT LOCATION
SAN JUAN HARBOR
SCALE
1
0
1
2 MI
18° 25'
WAVE REFRACTION
GRID LIMITS

PLATE A1

WAVE REFRACTION
WAVE PERIOD....6.0 SECONDS
DEEPWATER DIRECTION...NORTHWEST

PLATE A2



WAVE REFRACTION

WAVE PERIOD....8.0 SECONDS

DEEPWATER DIRECTION..NORTHWEST

PLATE A3

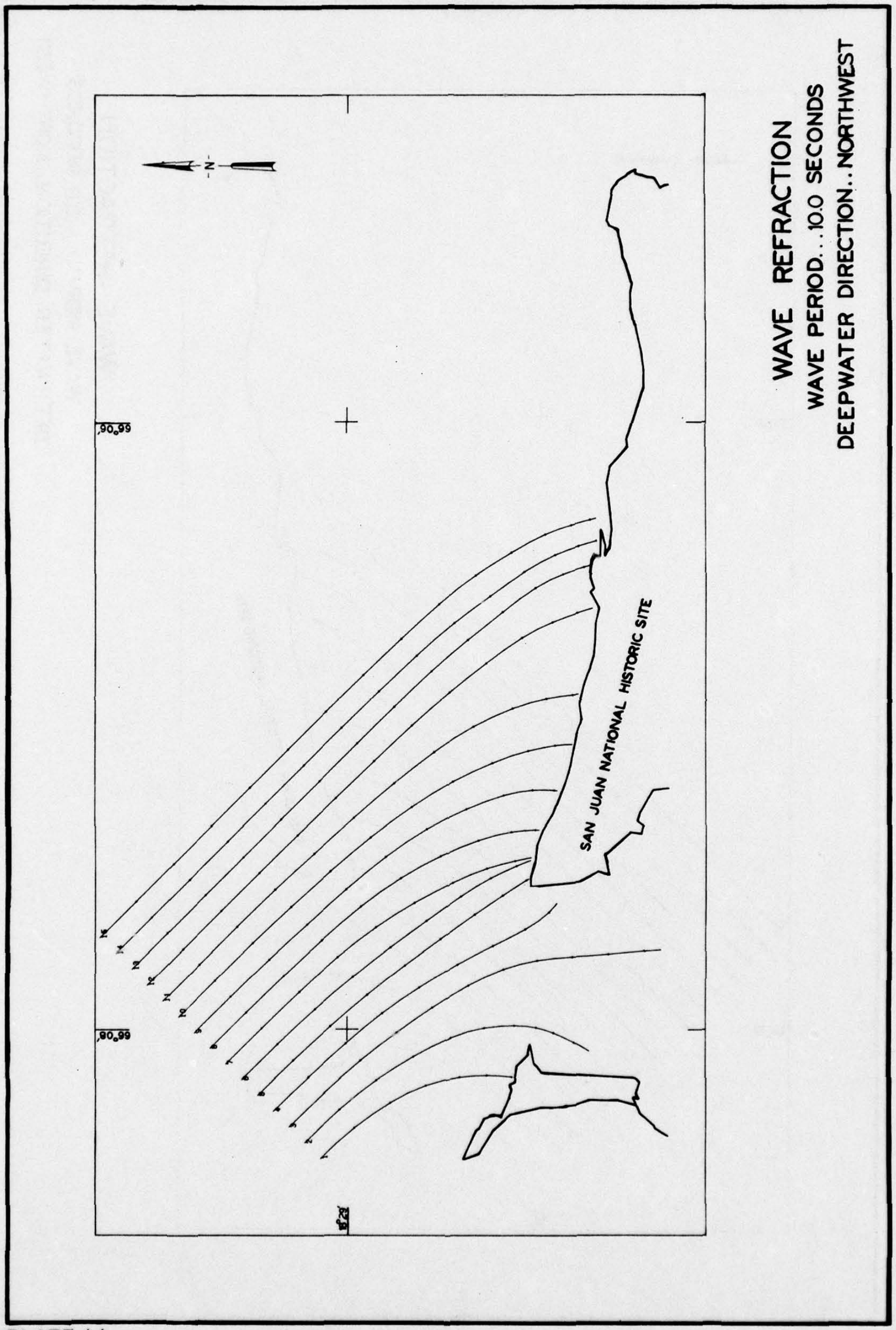

WAVE REFRACTION
WAVE PERIOD...10.0 SECONDS
DEEPWATER DIRECTION..NORTHWEST
SAN JUAN NATIONAL HISTORIC SITE
N

PLATE A4

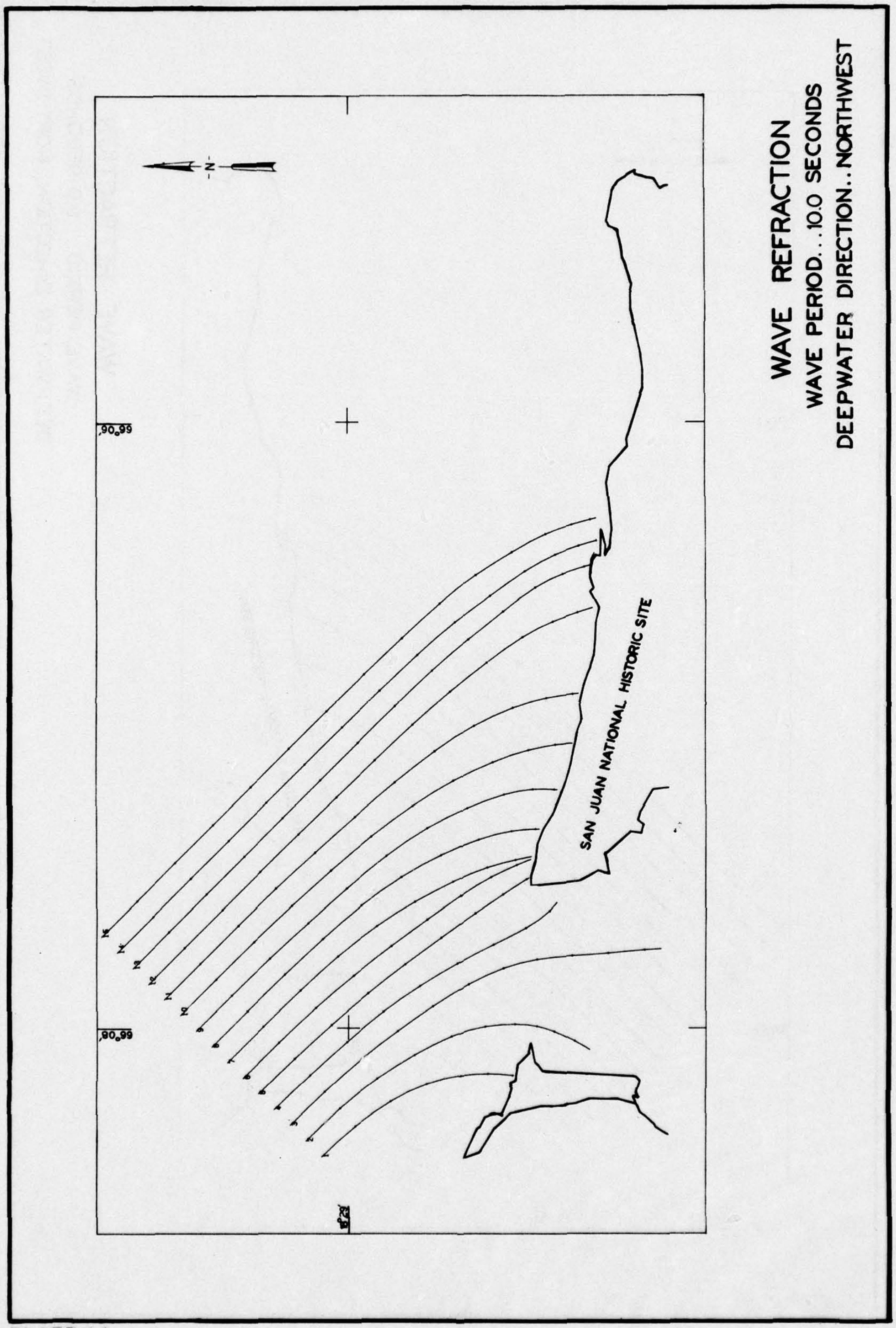
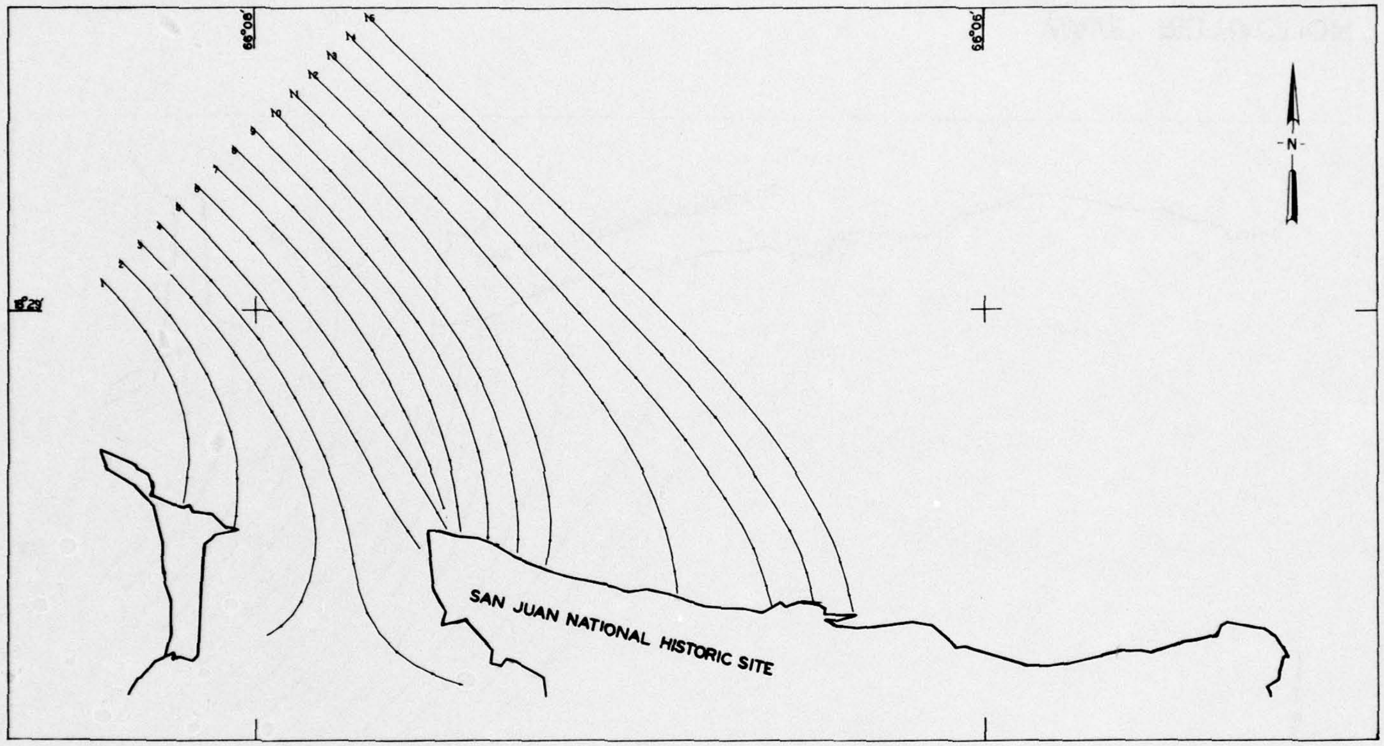

WAVE REFRACTION
WAVE PERIOD...10.0 SECONDS
DEEPWATER DIRECTION..NORTHWEST
SAN JUAN NATIONAL HISTORIC SITE
N

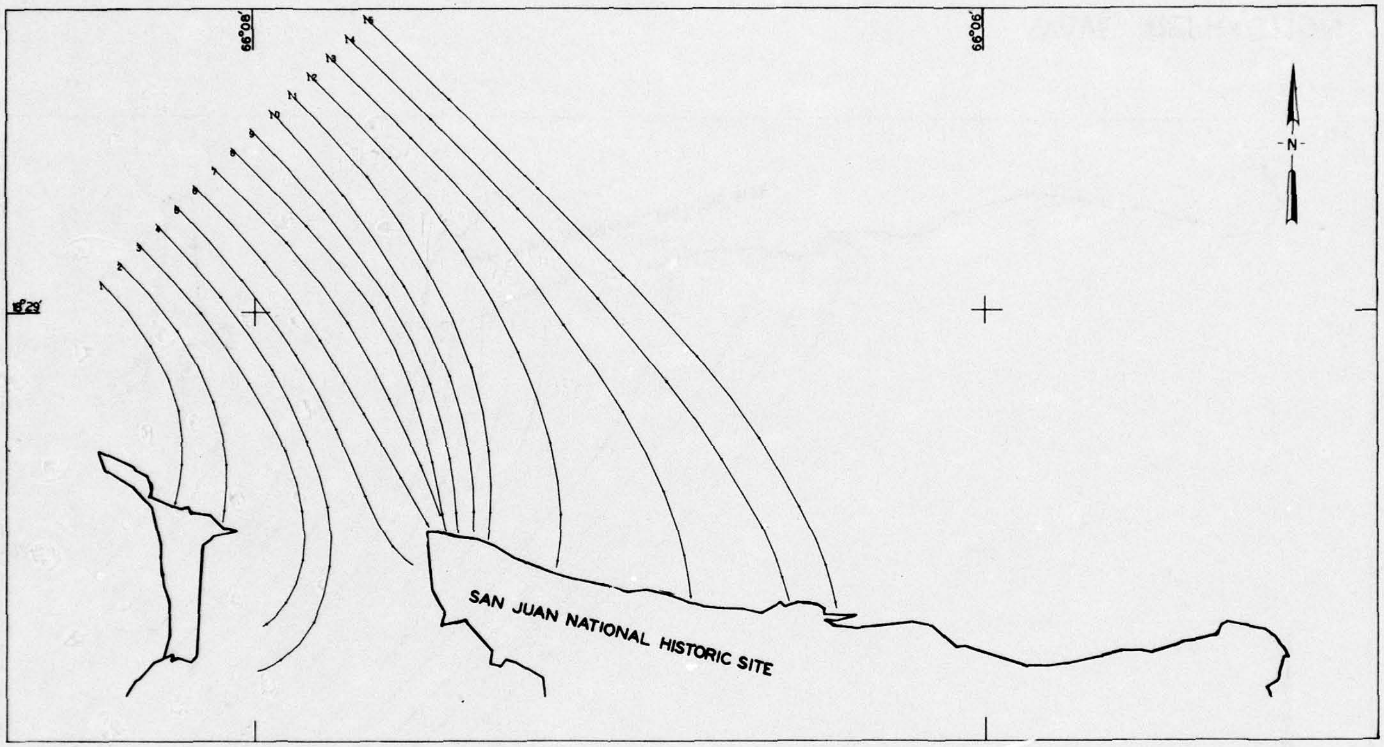
PLATE A4



WAVE REFRACTION

WAVE PERIOD...12.0 SECONDS

DEEPWATER DIRECTION..NORTHWEST

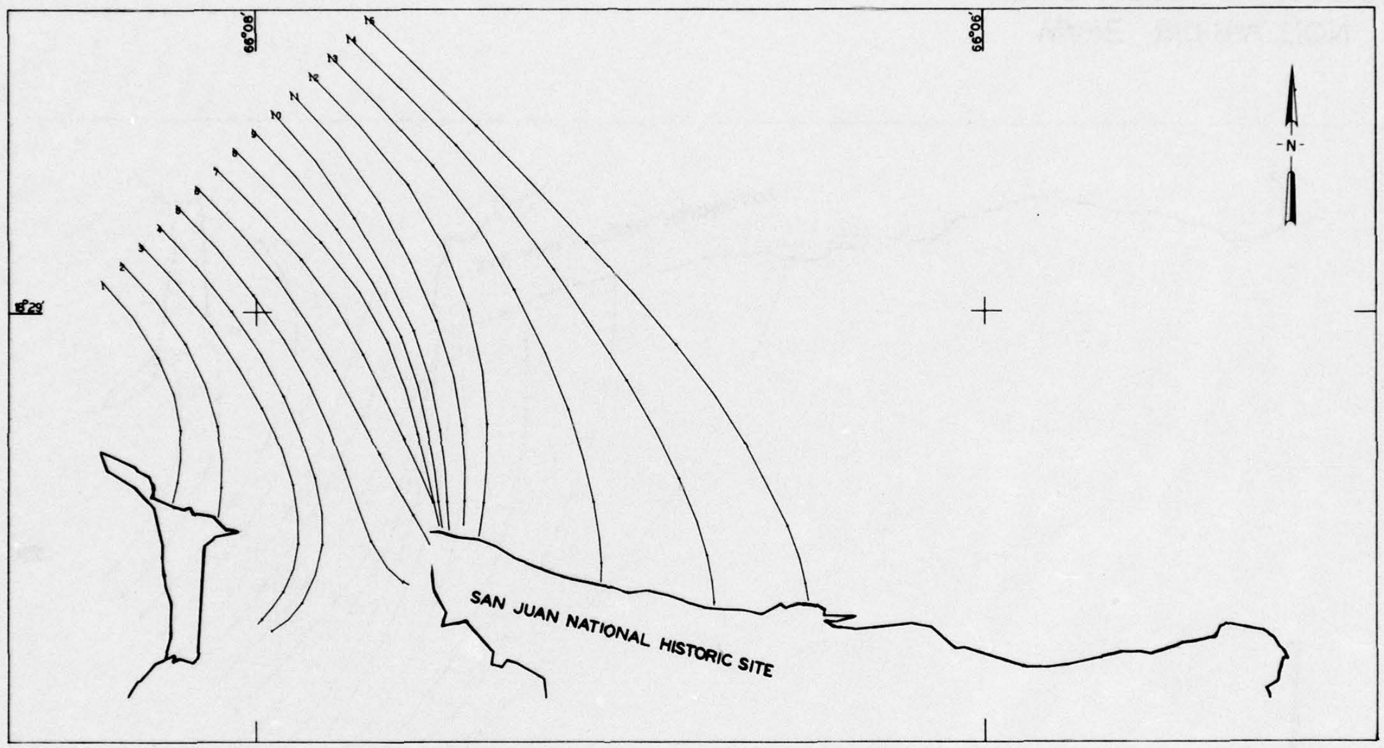


WAVE REFRACTION

WAVE PERIOD...14.0 SECONDS

DEEPWATER DIRECTION..NORTHWEST

PLATE A6



WAVE REFRACTION

WAVE PERIOD...16.0 SECONDS

DEEPWATER DIRECTION..NORTHWEST

PLATE A7

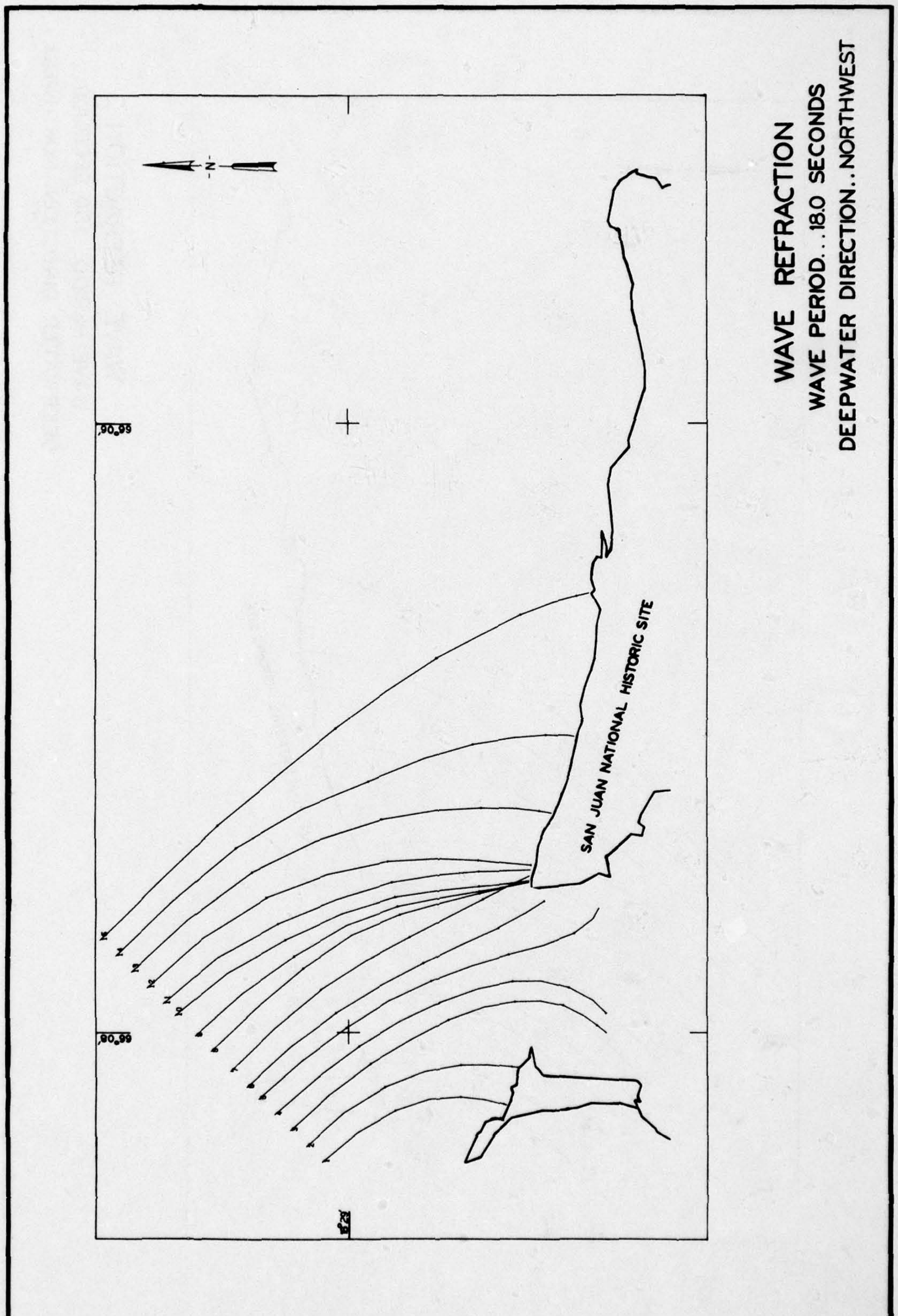
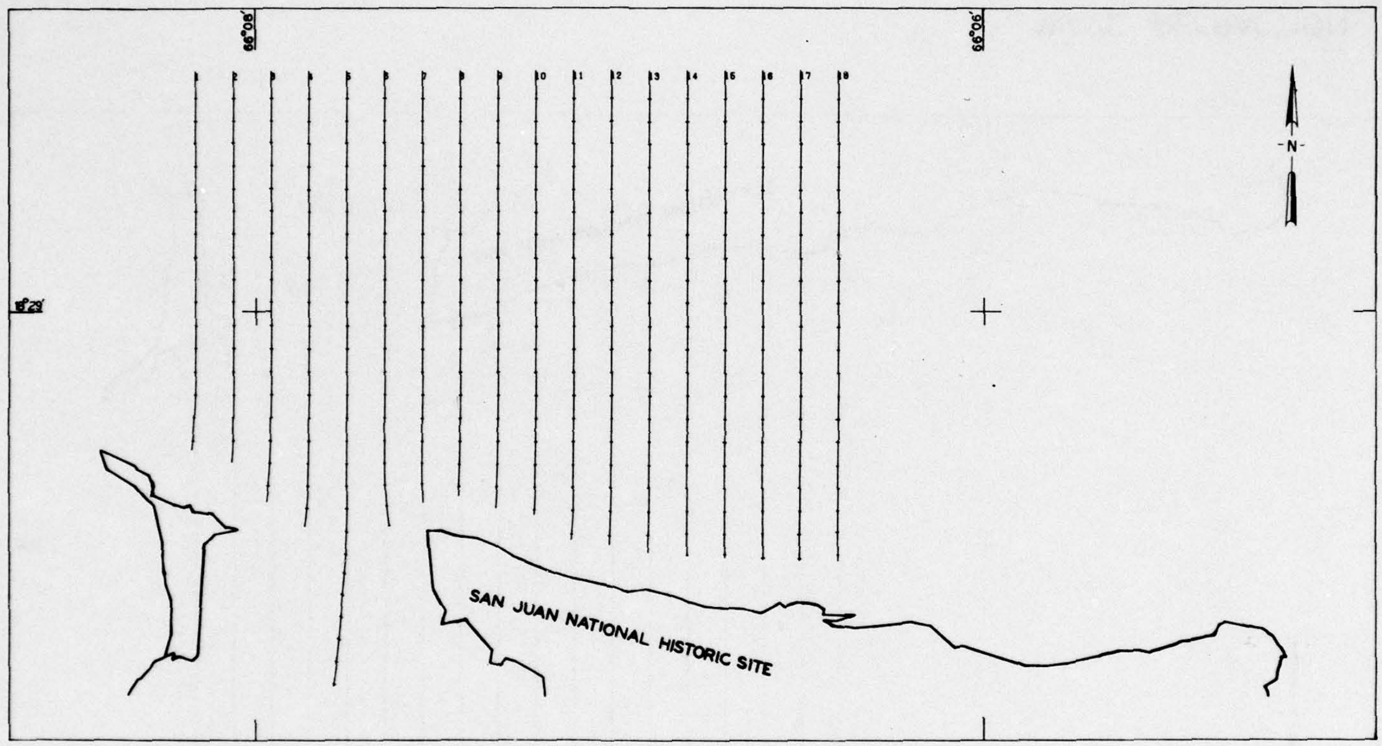

WAVE REFRACTION
WAVE PERIOD..18.0 SECONDS
DEEPWATER DIRECTION..NORTHWEST
SAN JUAN NATIONAL HISTORIC SITE
N

PLATE A8

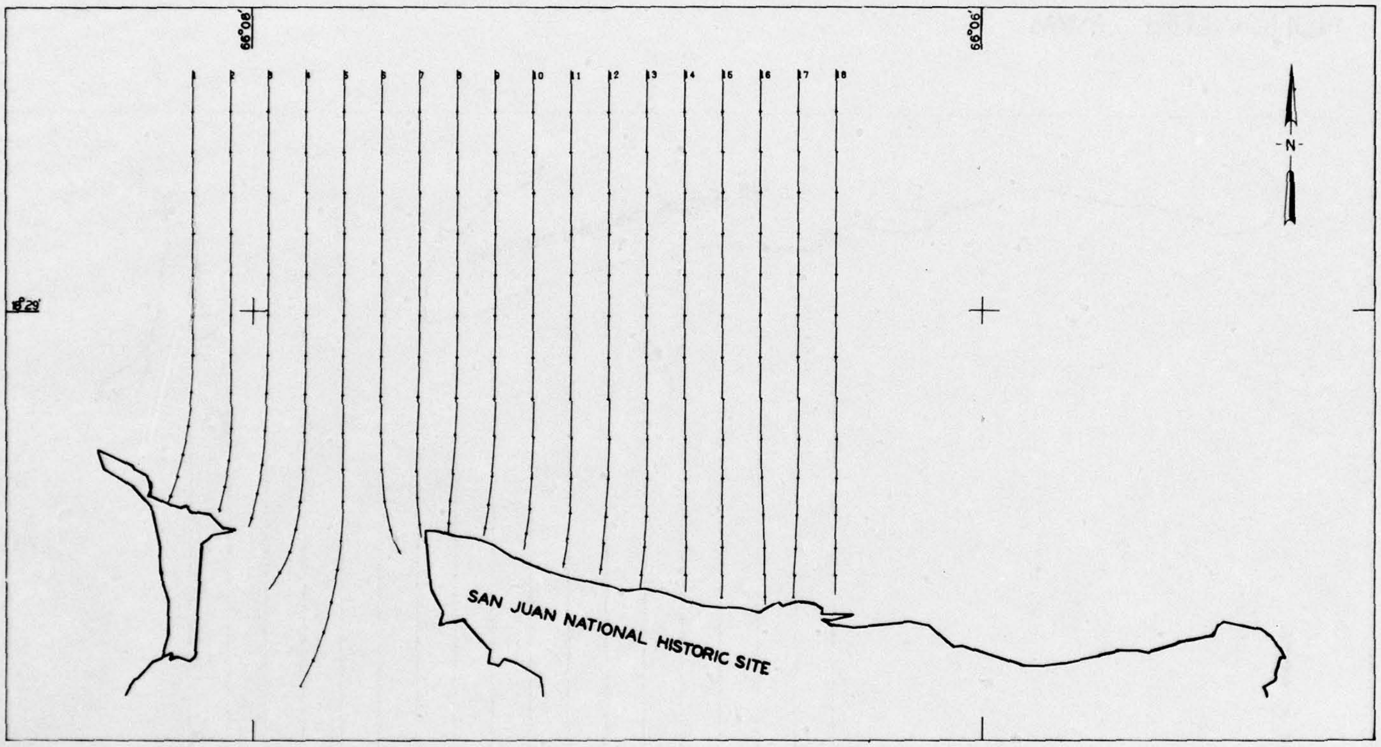


WAVE REFRACTION

WAVE PERIOD....6.0 SECONDS

DEEPWATER DIRECTION....... NORTH

PLATE A9

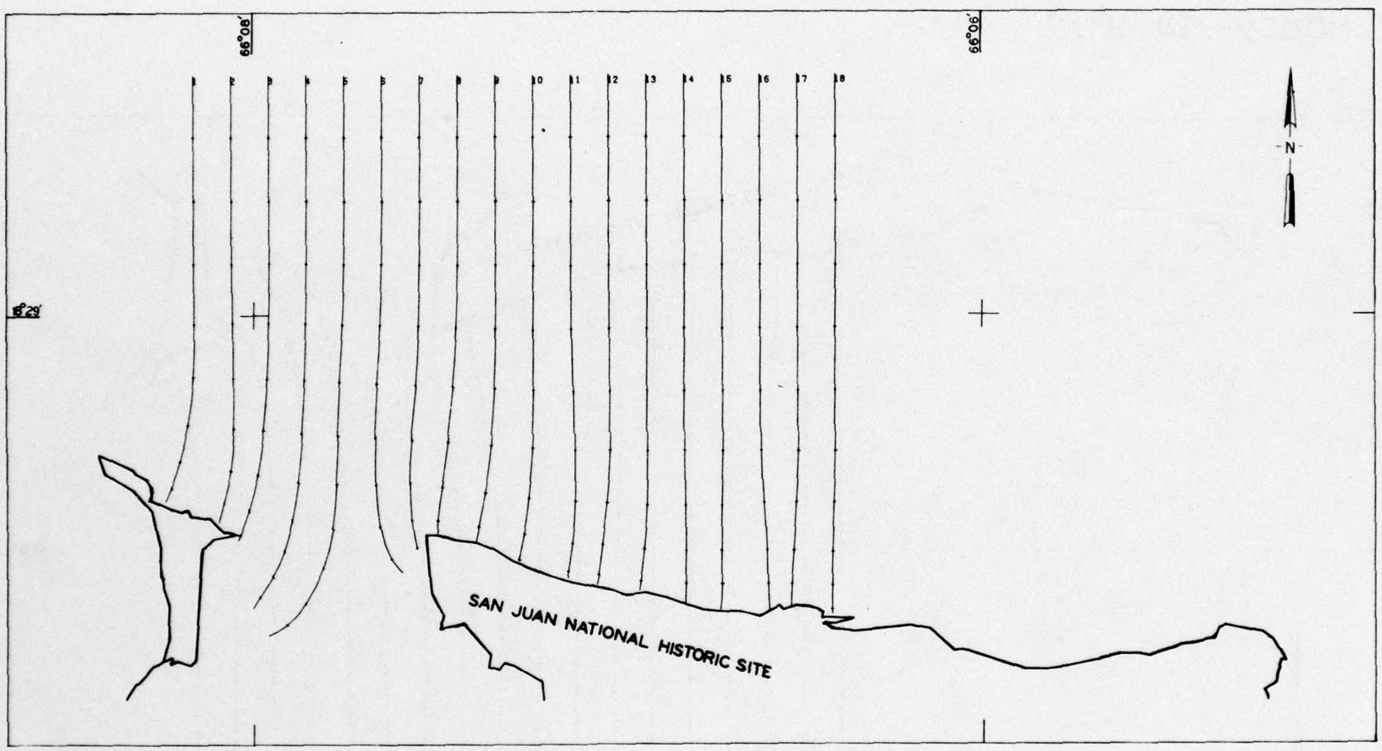


WAVE REFRACTION

WAVE PERIOD....8.0 SECONDS

DEEPWATER DIRECTION.......NORTH

PLATE A10



WAVE REFRACTION

WAVE PERIOD...10.0 SECONDS

DEEPWATER DIRECTION.......NORTH

PLATE A11

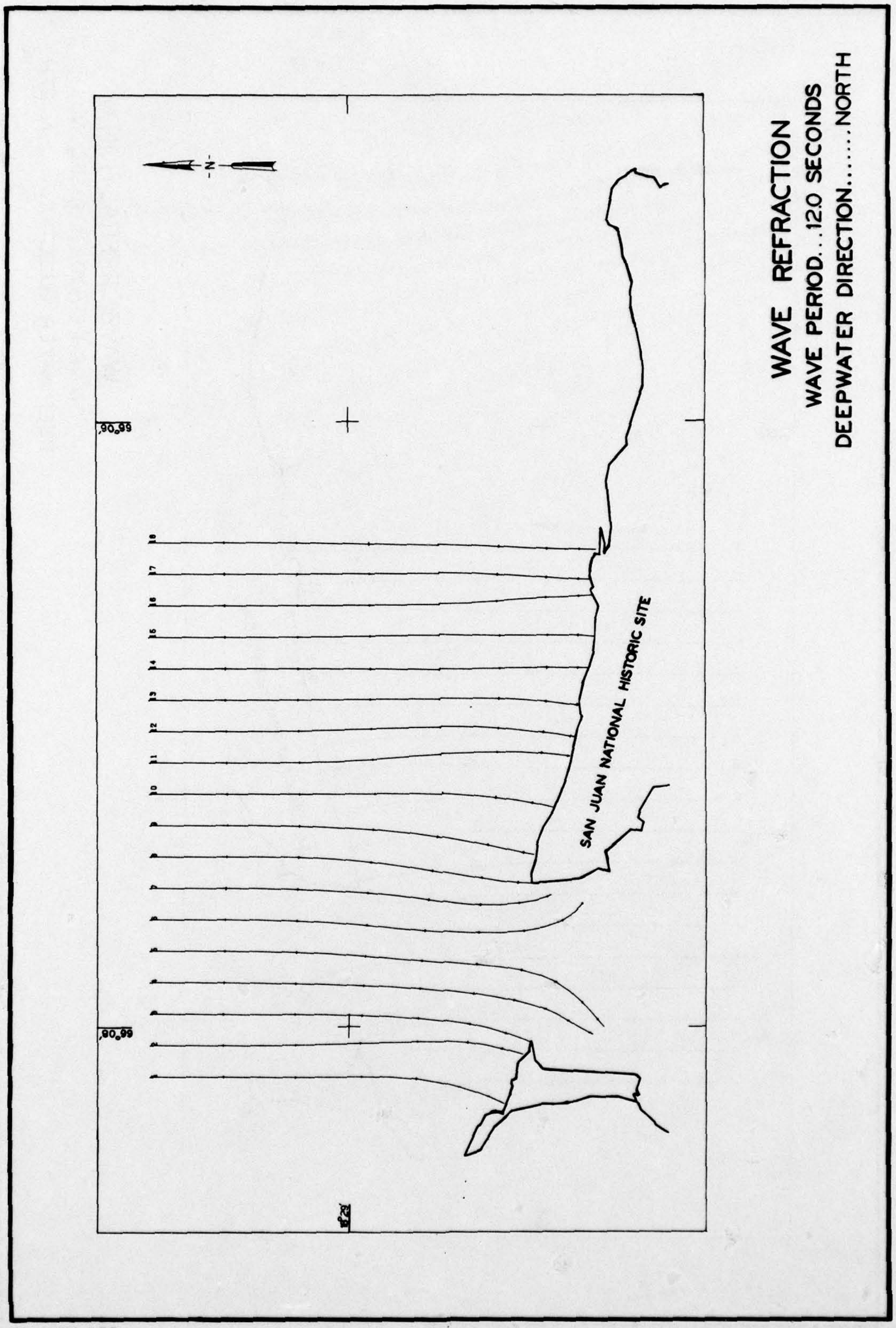
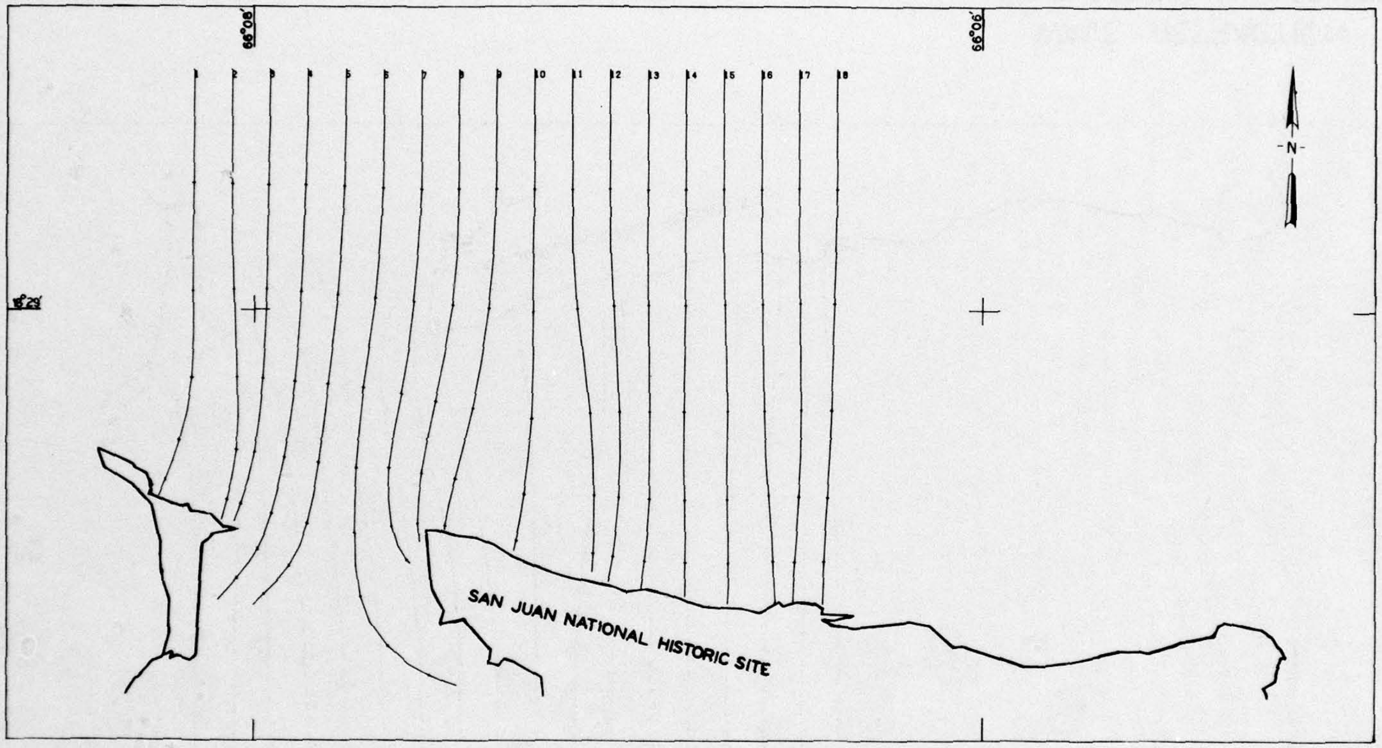

WAVE REFRACTION
WAVE PERIOD...12.0 SECONDS
DEEPWATER DIRECTION......NORTH
SAN JUAN NATIONAL HISTORIC SITE
N

PLATE A12



WAVE REFRACTION

WAVE PERIOD...14.0 SECONDS

DEEPWATER DIRECTION....... NORTH

PLATE A13

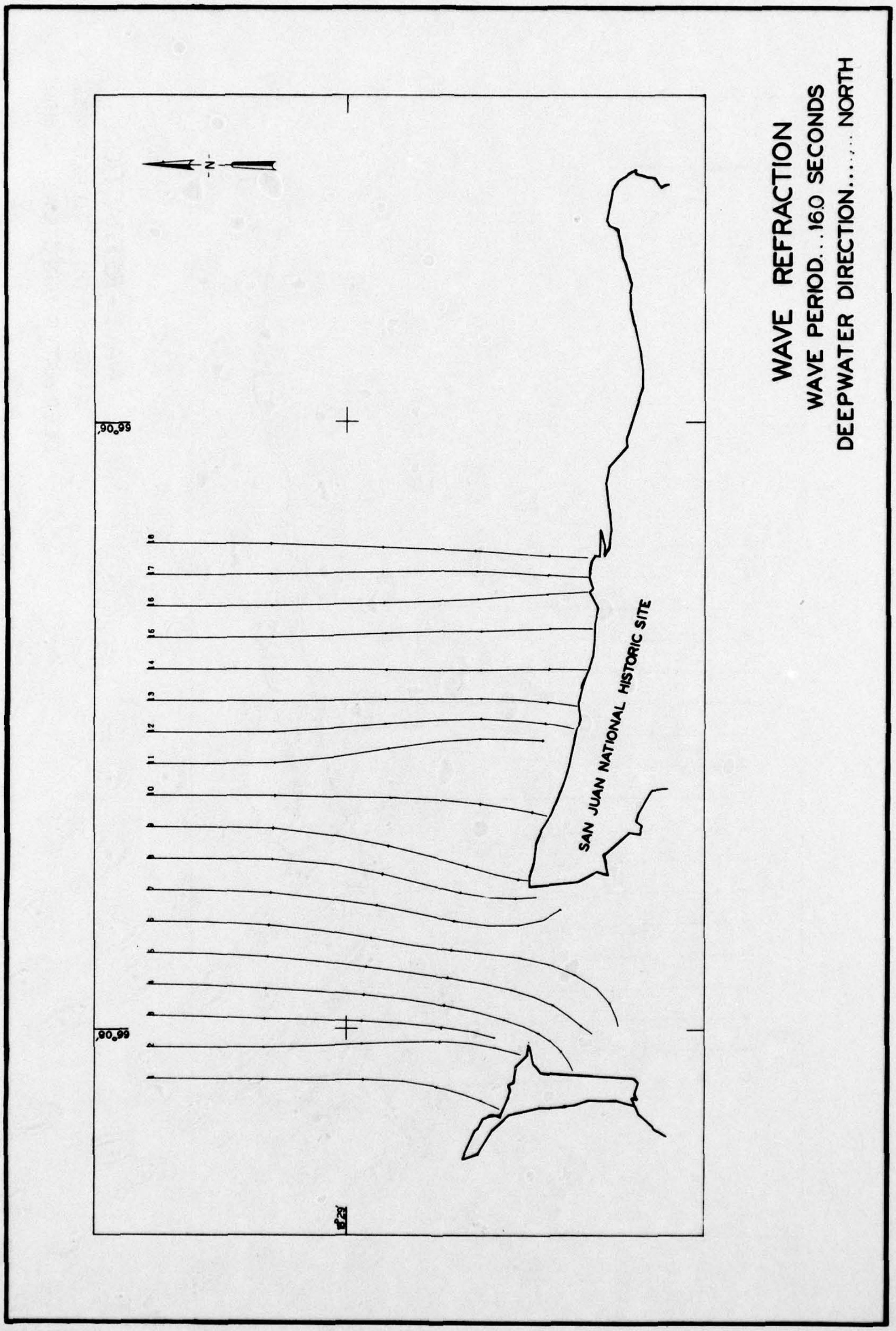
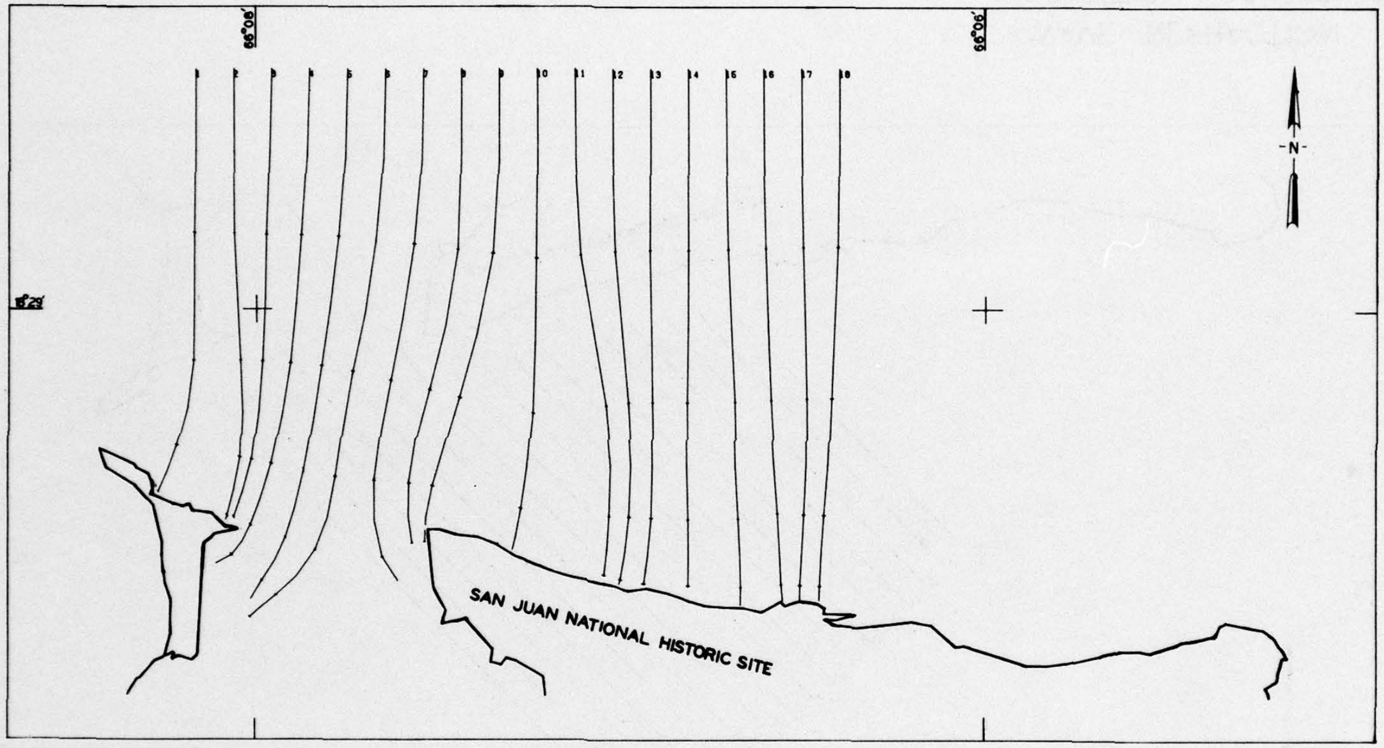

WAVE REFRACTION
WAVE PERIOD...16.0 SECONDS
DEEPWATER DIRECTION....... NORTH
SAN JUAN NATIONAL HISTORIC SITE
N

PLATE A14

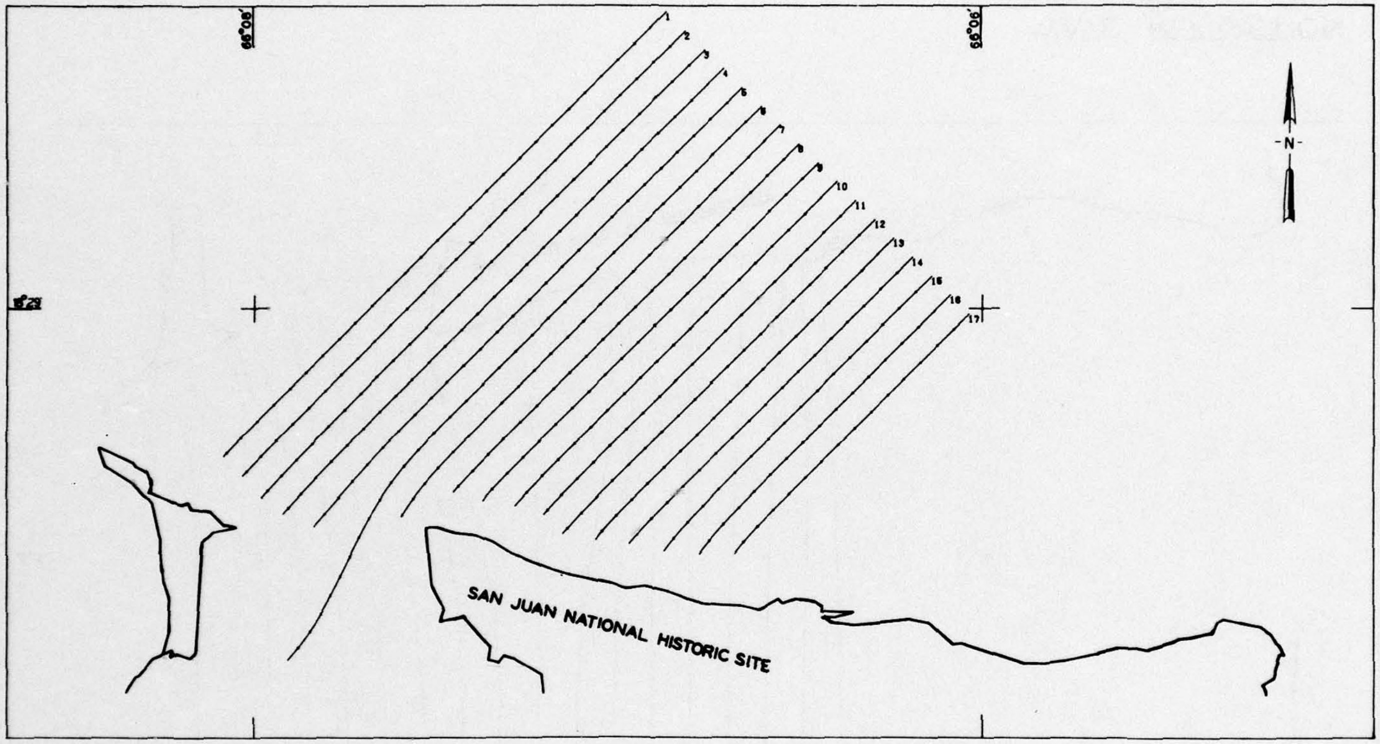


WAVE REFRACTION

WAVE PERIOD...18.0 SECONDS

DEEPWATER DIRECTION....... NORTH

PLATE A15

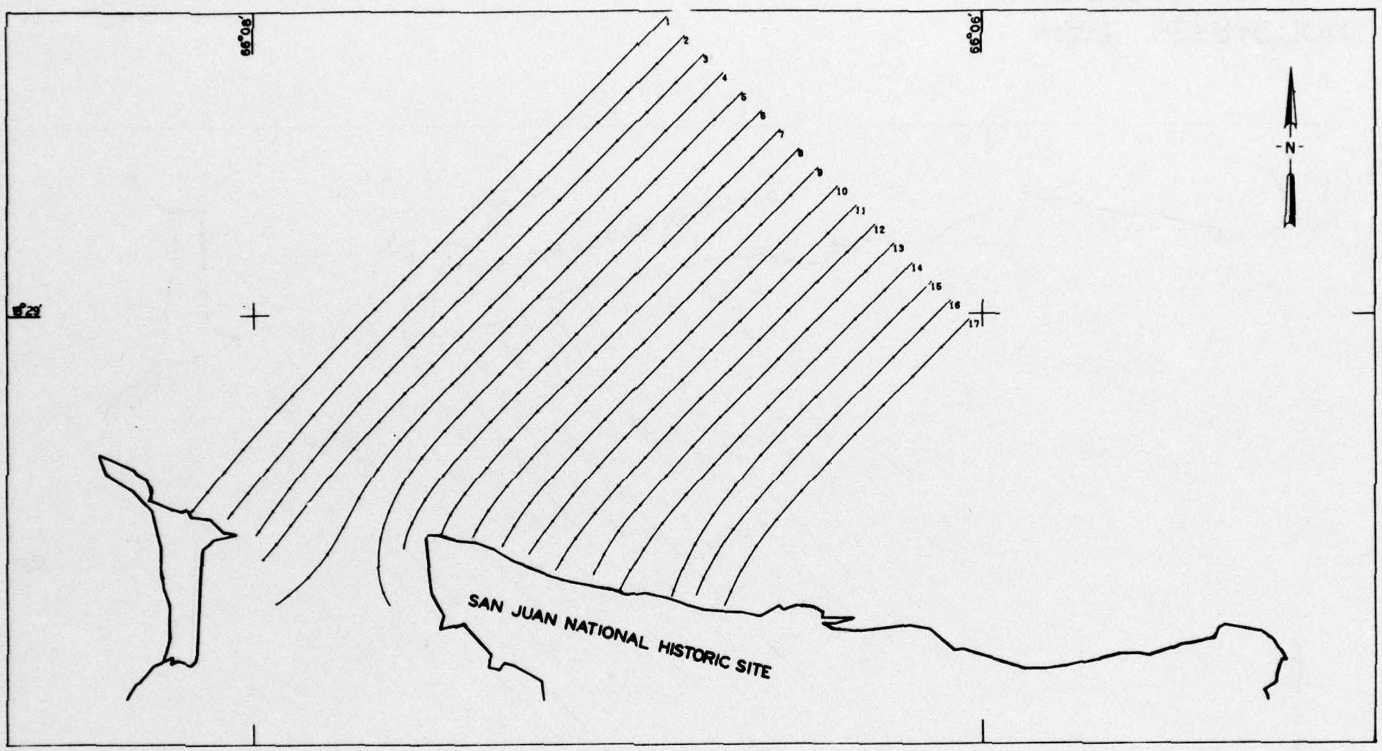


WAVE REFRACTION

WAVE PERIOD....6.0 SECONDS

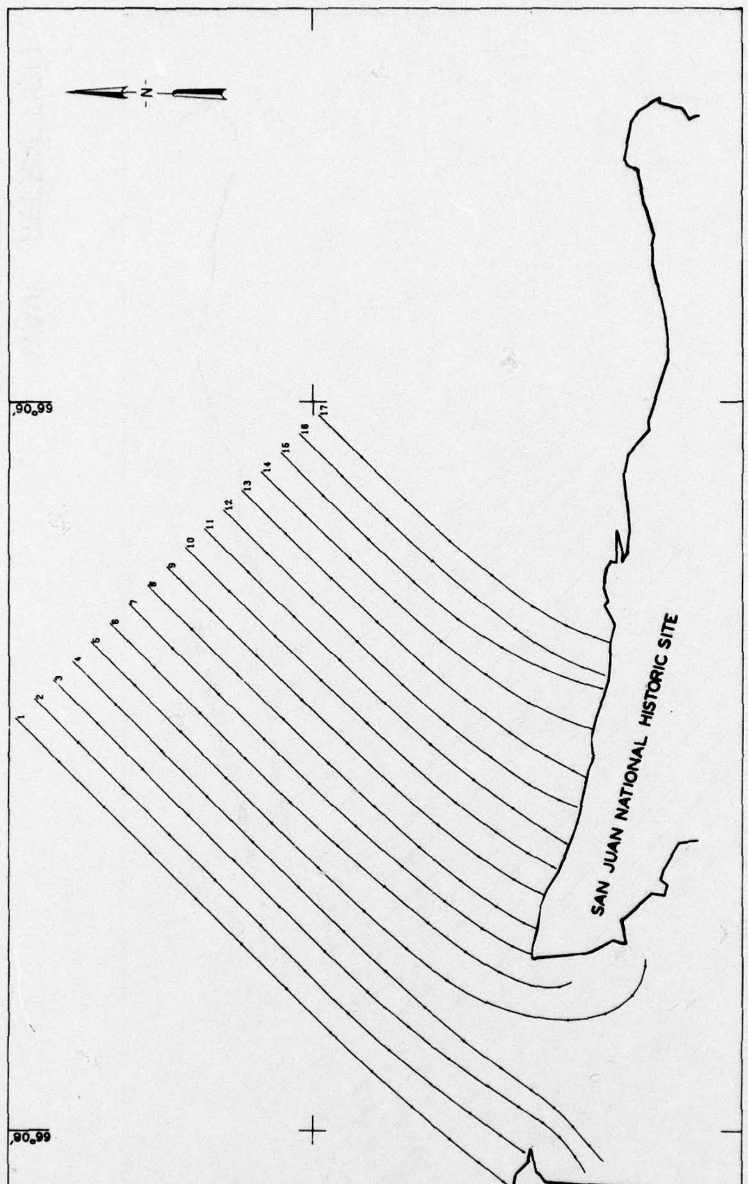
DEEPWATER DIRECTION...NORTHEAST

PLATE A16



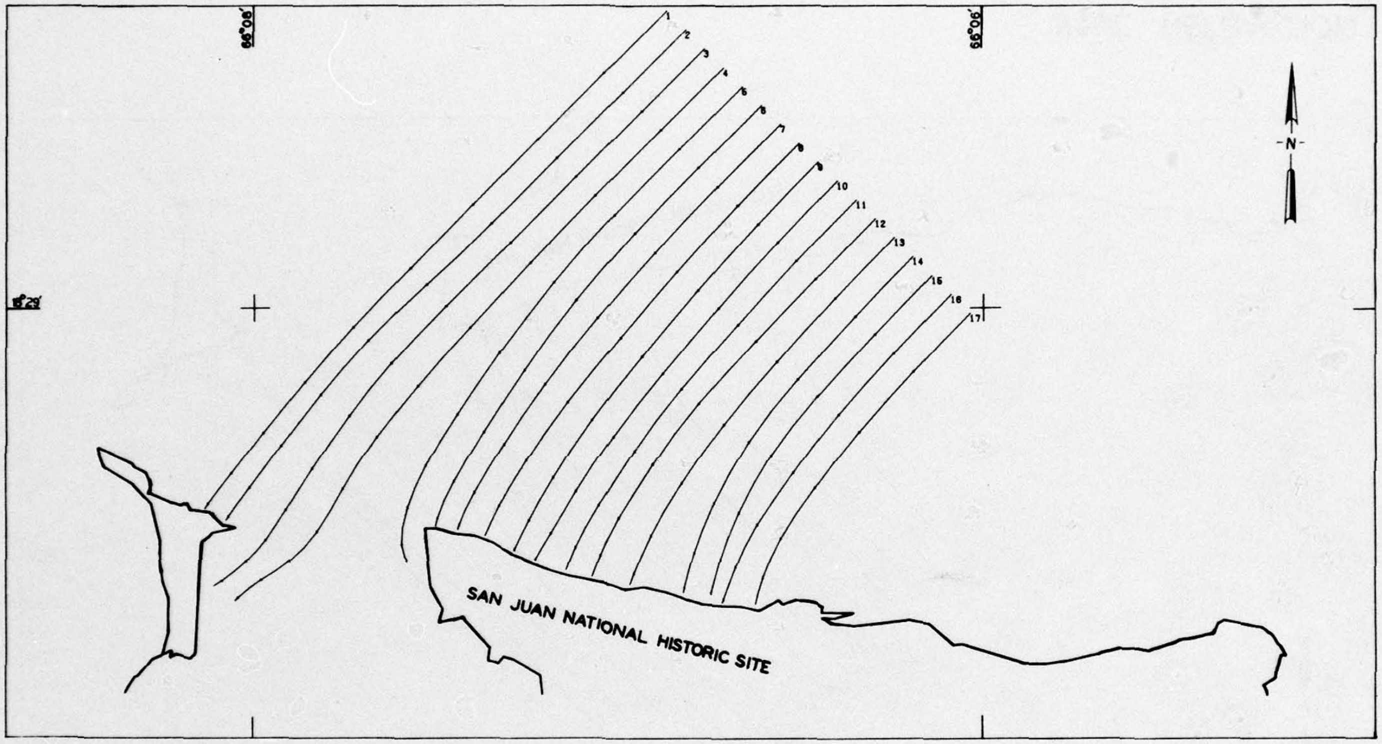
WAVE REFRACTION
WAVE PERIOD....8.0 SECONDS
DEEPWATER DIRECTION...NORTHEAST

PLATE A17



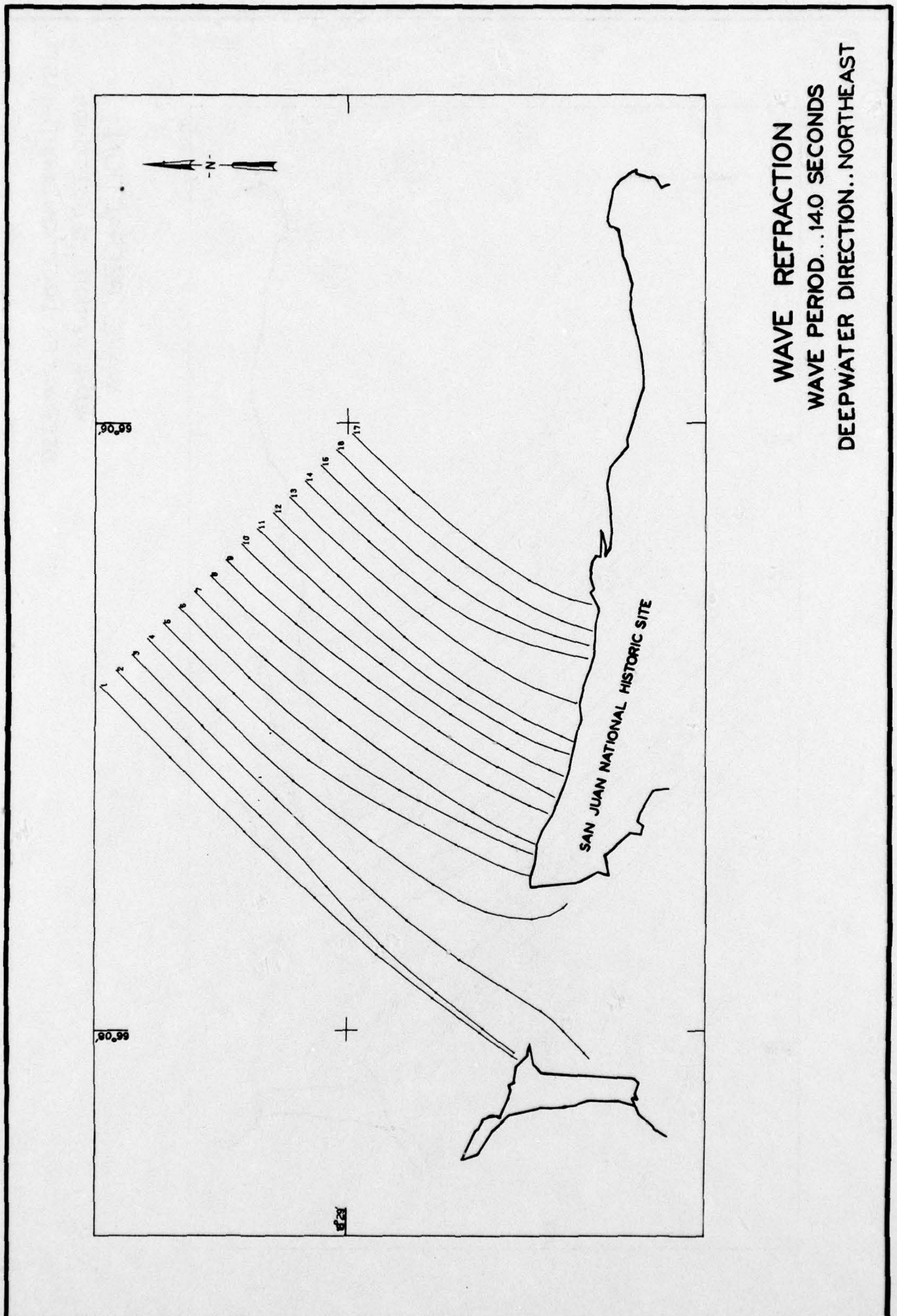
WAVE REFRACTION
WAVE PERIOD... 10.0 SECONDS
DEEPWATER DIRECTION..NORTHEAST

PLATE A18



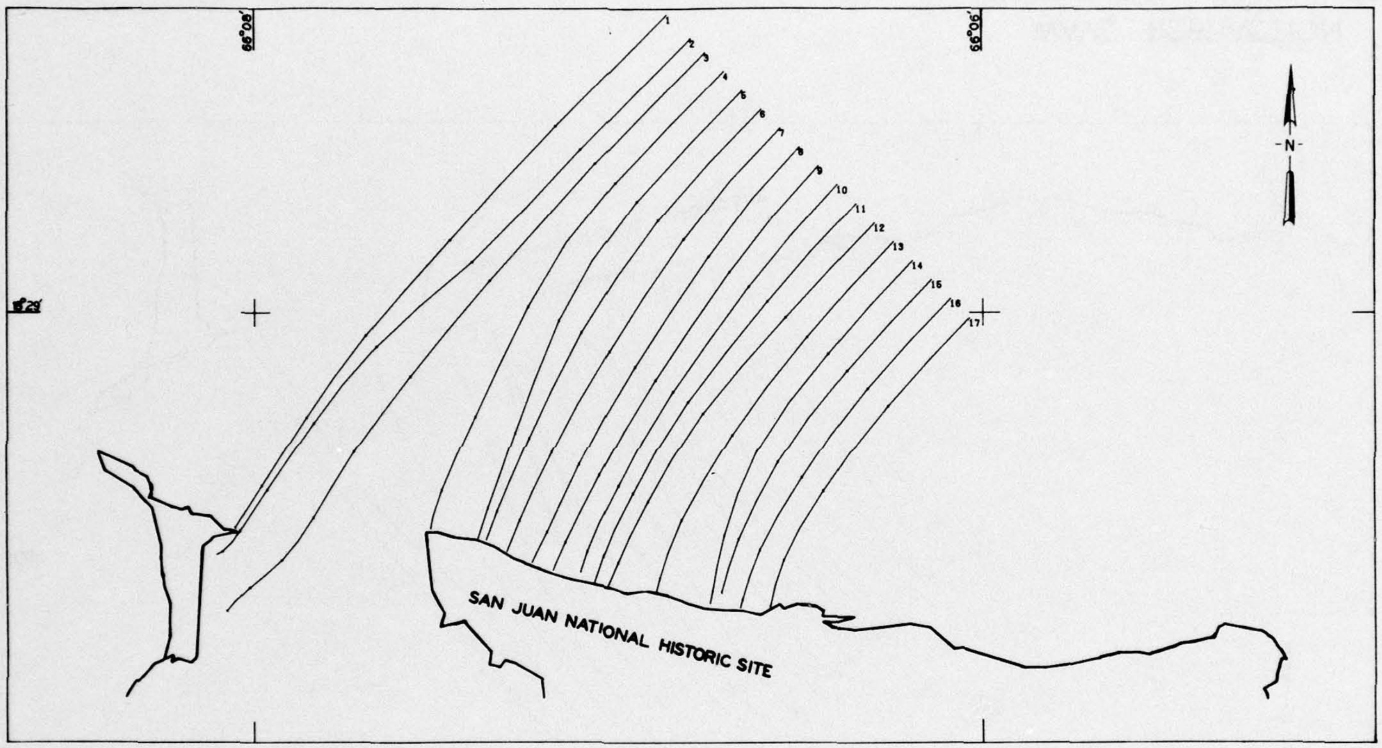
WAVE REFRACTION
WAVE PERIOD...12.0 SECONDS
DEEPWATER DIRECTION..NORTHEAST

PLATE A19



WAVE REFRACTION
WAVE PERIOD..14.0 SECONDS
DEEPWATER DIRECTION..NORTHEAST
SAN JUAN NATIONAL HISTORIC SITE
N

PLATE A20

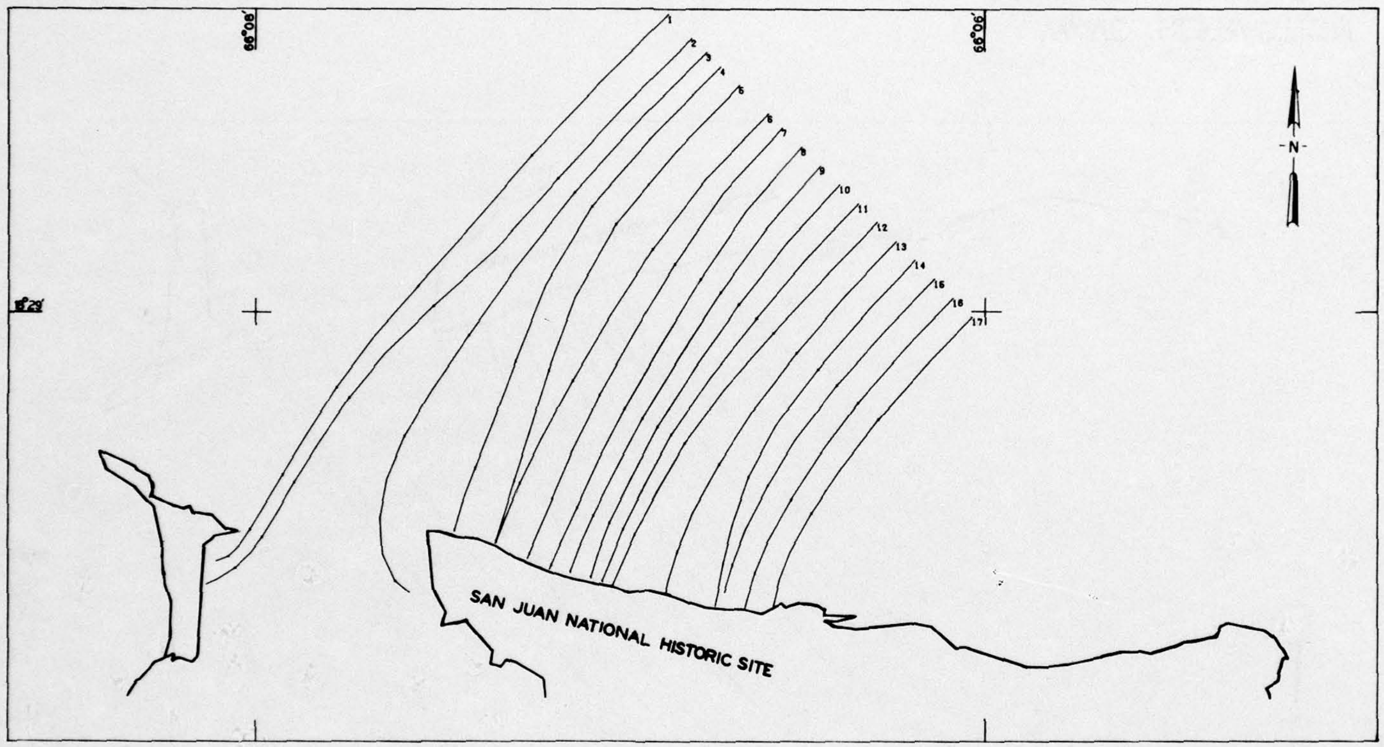


WAVE REFRACTION

WAVE PERIOD...16.0 SECONDS

DEEPWATER DIRECTION..NORTHEAST

PLATE A22



WAVE REFRACTION

WAVE PERIOD...18.0 SECONDS

DEEPWATER DIRECTION..NORTHEAST

APPENDIX B: NOTATION

A	Area
b	Shallow-water othogonal spacing
b_o	Deepwater orthogonal spacing
$(b_o/b)^{1/2}$	Refraction coefficient, K_r
H	Shallow-water wave height
H_o	Deepwater wave height
$H_{1/3}$	Significant wave height
K_r	Refraction coefficient
K_s	Shoaling coefficient
L	Length
T	Time
V	Velocity
$\cancel{V}$	Volume

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Bottin, Robert R
  San Juan National Historic Site, San Juan, Puerto Rico; design for prevention of wave-induced erosion; hydraulic model investigation / by Robert R. Bottin, Jr. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1979.
  34, [111] p., [207] leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-79-15)
  Prepared for U. S. Army Engineer District, Jacksonville, Jacksonville, Florida, and The National Park Service, Southeast Regional Office, U. S. Department of the Interior, Atlanta, Georgia.
  References: p. 34.

1. Breakwaters. 2. Erosion control. 3. Hydraulic models. 4. Revetment. 5. San Juan National Historic Site. 6. Water wave action on maritime structures. 7. Water waves.

(Continued on next card)

Bottin, Robert R
  San Juan National Historic Site, San Juan, Puerto Rico; design for prevention of wave-induced erosion; hydraulic model investigation ... 1979. (Card 2)

I. United States. Army. Corps of Engineers. Jacksonville District. II. United States. National Park Service. Southeast Regional Office. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-79-15.
TA7.W34 no.HL-79-15